Study of Tug Escorts in Puget Sound

Prepared for
State of Washington: Department of Ecology
Lacey, Washington

File No. 04075
December 2004

THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community

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EXPIRES 1/07/2006

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EXECUTIVE SUMMARY

This report presents the results of an analysis of the Washington State tug escort system by The Glosten Associates, Inc., in conjunction with Herbert Engineering Corporation, Dr. Martha Grabowski and Environmental Research Consulting. The analysis was requested by the Spill Prevention, Preparedness and Response Program of the Washington State Department of Ecology (WDOE). The study is an "evaluation of tug escort requirements for laden tankers to determine if the current escort system requirements under RCW 88.16.190 should be modified to recognize safety enhancements of the new double-hull tankers deployed with redundant systems." The WDOE request is contained in RFP Number ECY RFP 0414, Project Title: "Study of Tug Escorts in Puget Sound."

This report contains the results for each of the objectives listed in Section 1.2 of the subject RFP. They are:

- Describe the present tug escort requirements as stated in the Washington State Pilotage Act.
- Describe how tankers are currently escorted in subject waters.
- Describe the environmental and economic values potentially protected by the current escort system.
- Describe the capabilities and limitations of double-hull, single-propulsion tankers (and their escort tugs) that presently call in the subject waters.
- Describe the phase-out of single-hull tankers; the anticipated change in use of tank barges and articulated tug - barge vessels.
- Describe the safety enhancements of the new, double-hull tankers deployed with redundant systems that presently call in the subject waters.
- Describe the range of technological, human and external factors that influence risk management as it applies to the tug escort system.
- Compare Washington State Pilotage Act and current Puget Sound practice to other tug escort systems, such as Prince William Sound and California escort requirements.
- Identify any effects of proposed changes to the tug escort system on the population of capable tugs in Puget Sound.
- Prepare a report of findings from the study and make recommendations for escorting the new, double-hull tankers with redundant systems in the subject waters.
- Prepare an analysis of the anticipated safety, environmental and economic consequences of the draft recommendations.

The results, findings and draft recommendations contained herein are the result of a careful study by the authors of the above listed components. There is a section in this report covering each of these topics.

In addition, the WDOE set the condition under which a recommendation to change RCW 88.16.190 for double-hull tankers deployed with redundant systems could be made. The standard of acceptable risk set for this study is the level of oil outflow from an IMO minimally compliant, double-hull, single-screw tanker loaded to 125,000 dwt (deadweight tons) with tug escort.

FINDINGS

Double-hull, redundant-system tankers are a significant positive technological step toward improving safety of oil transport in Puget Sound waters and elsewhere. The double hulls significantly reduce the probability and volume statistics of oil outflow into the environment in the event of a grounding or collision. Their fully redundant systems for propulsion and steering significantly reduce the probability that a mechanical failure will result in the loss of control of the vessel.

These vessels can maintain exceptional control even with the loss of one steering system or one propulsion system; or one steering system *and* one propulsion system on the same side. It can be demonstrated that if these vessels are operating in their fully redundant mode and there is a single-system failure (steering or propulsion), even in severe wind and wave conditions that can occur in Puget Sound, there is a high probability that a grounding can be averted.

However, a redundant-system tanker disabled by the failure of both propulsion systems or both steering systems is not expected to be able to avert grounding without tug escort.

The complete mechanical loss of control of a redundant-system tanker, e.g., loss of both engines or loss of both rudders or one engine /one rudder on opposite sides, is an extremely rare event. It is estimated in this study that the probability of grounding (without tug escort) from these failures within 4 hours of each other is in the range of 3 to 7 x 10^{-7} (3 to 7 in 10,000,000 transits.) This is in the range of 1 occurrence in 980 to 2,300 years of transits in Puget Sound, assuming an average transit time of 6 hours.

A twin-screw tug escort for single-screw tankers that is configured based on the RCW 88.16.190/195 and, more importantly, in voluntary compliance with the Puget Sound Harbor Safety and Security Committee (PSHSSC) "Harbor Safety Plan" of August 1, 2003 can reasonably be expected to prevent the grounding of a single-screw tanker in the event of a propulsion or steering failure on the tanker.

Tug escort of a single-screw tanker may not be able to prevent a grounding if the tug experiences a propulsion or steering failure within 4 hours of the propulsion or steering failure on the tanker. The incident rate for a two-system failure of this type is calculated in this study to be in the range of 3 to 4 x 10^{-7}.

However, even with a single propulsion failure on the escort tug, there is residual capability available to a twin-screw tug to prevent a grounding. For a rudder failure on a 125,000 dwt, Suezmax single-screw tanker transiting at a speed appropriate to the waterway width and escorted by a 6,250 hp, twin-screw tug with one engine failure predict that in some locations a grounding can still be prevented; further reducing the probability of grounding presented in the previous paragraph.

The incident rate for multiple system failures is several orders of magnitude less than for a single system failure. A two-system failure disables a redundant-system tanker if the second failure occurs simultaneously or shortly after the first failure. The estimates developed in this study assume that a second failure within 4 hours of the first failure will, without tug intervention, result in a grounding. (The 4 hour assumption is discussed in Section 10.)

The probability of grounding due to propulsion or steering failures of a redundant-system tanker without escort and a single-screw tanker with escort are both very small (between 10^{-6} to 10^{-7} per transit). The redundant-system tanker without escort is estimated to have a slightly higher probability of grounding. These estimates and their difference do not include human factor risks.

The probabilities of oil outflow from identically configured double-hull, single-screw <u>or</u> double-hull, redundant-system tankers are the same if there is a grounding. Therefore, the difference between escort of single screw tankers and non-escort of redundant system tankers can only be found in other factors.

The difference in risk of oil outflow between escorted single-screw tankers and non-escorted redundant-system tankers can only be identified by further study of mechanical-failure incident rates and particularly a comprehensive human factors analysis.

<u>RECOMMENDATIONS</u>

The analysis contained in this study does not quantitatively show that the standard of safety proposed by the Washington State Department of Ecology for this study can be maintained if the requirement for tug escorts for redundant-system tankers is totally eliminated in the waters of Puget Sound currently subject to escort. The authors of this study do not at this time recommend changes to RCW 88.16.190 that would totally eliminate escorts for redundant-system double-hull tankers.

It is the recommendation of the authors of this report that a decision for or against the elimination of tug escort for redundant system tankers can only be made if a human factors study is undertaken.

The authors further conclude that the requirements in state law RCW 88.16.190/195, as it now stands, are inadequate to ensure a tug escort that can reasonably be expected to avert a tanker grounding in the event of a propulsion or steering failure. Other than the horsepower requirement, RCW 88.16.190/195 and WAC 363-116-500 do not specify a performance standard for escort tugs.

It is the opinion of the authors that the law should, as a minimum, contain provisions that require that the escort tugs be twin-screw vessels. In addition, it is the opinion of the authors that the law should specify that the selection of escort tug(s) be in accordance with the American Society for Testing and Materials (ASTM) *Standard Guide for Escort Vessel Evaluation and Selection*, Designation: F1878–98, adopted 1998.

The authors question whether the federal 125,000 dwt limit for tankers entering Puget Sound minimizes oil outflow risk in the event of a grounding. The relative risks of oil outflow from more frequent transits of partially-laden (deadweight-limited), double-hull tankers should be compared to less frequent transits of double-hull, fully-laden tankers. The authors recognize that the 125,000 dwt limit for tankers entering certain waters of Puget Sound is contained in federal legislation that supersedes Washington State jurisdiction (see RCW 88.16 and holding in U.S. Supreme Court ruling in ARCO v. Ray) on this issue.

The authors recommend that tanker deadweight tonnage limits for Puget Sound be considered for further study.

A member of the Tug Escort Steering Committee for this project proposed that a sentinel tug system be evaluated. The sentinel tug system was proposed as an alternative to either maintaining or eliminating the current RCW 88.16.190 requirement for tug escort for redundant-system tankers.

A sentinel tug would meet the condition set by WDOE; that the system be as safe as a conventional double-hulled tanker with a state compliant single-tug escort. The authors of this study recommend that this alternative be considered for escorting redundant-system tankers, provided it is developed as part of an overall system to reduce risk of oil spill for tanker transits of Puget Sound. A sentinel tug system is not recommended for single-screw tankers.

1 INTRODUCTION

This report presents the work performed to evaluate the current tanker escort requirements in Washington State with respect to the escort of redundant-system tankers. The objective of the study is to determine whether the current escort system requirements for laden tankers under RCW 88.16.190 should be modified to recognize safety enhancements of new double-hull tankers deployed with redundant systems. Redundant-system tankers have, as a minimum, two independent propulsion systems and two independent steering systems (rudders). They are frequently referred to as twin-screw tankers. A complete discussion of various definitions of redundant-system ships is presented in Section 7.

The escort by tugs of laden oil tankers in Washington waters is currently governed by RCW 88.16.190. This set of regulations first entered force in 1975 and was last amended in 1994. The current practice for tanker escort is also governed by Federal laws contained in and arising out of the Oil Pollution Act of 1990 (OPA 90). However, the OPA 90 regulations do not require escort of double-hull tankers, and thus these vessels are subject only to RCW 88.16.190.

With the arrival of double-hull tankers with redundant systems (twin-screw, twin-rudder), the question has been asked if maintaining the Washington State escort requirements in their current form is a reasonable requirement for these vessels.

The scope of work undertaken is as follows:

- Describe the present tug escort requirements as stated in the Washington State Pilotage Act.
- Describe how tankers are currently escorted in the subject waters.
- Describe the environmental and economic values potentially protected by the current escort system.
- Describe the capabilities and limitations of double-hull, single-propulsion tankers (and their escort tugs) that presently call in the subject waters.
- Describe the phase-out of single-hull tankers and the anticipated change in the use of tank barges and articulated tug---barge vessels.
- Describe the safety enhancements of the new double-hull tankers deployed with redundant systems that presently call in the subject waters.
- Describe the range of technological, human and external factors that influence risk management as it applies to the tug escort system.
- Compare the Washington State Pilotage Act and current Puget Sound practice with other tug escort systems in place in other parts of the country and around the world.

- Identify any effects of proposed changes to the tug escort system on the population of capable tugs in Puget Sound.

- Prepare a report of findings and make recommendations for escorting the new double-hull tankers with redundant systems in the subject waters.

- Prepare an analysis of the anticipated safety, environmental and economic consequences of the draft recommendations.

There is a section in this report covering each of these topics.

2 EXISTING TUG ESCORT REQUIREMENTS: HISTORY, AND RATIONALE

This section provides a brief history of and the rationale for the current escort system in Washington State waters.

Pilotage legislation in the United States dates back to the late 18th century. On August 7, 1789, the U.S. Congress passed an act for the establishment and support of lighthouses, beacons, buoys, and public powers. Included in the act was legislation empowering the respective states to regulate pilotage in the bays, inlets, rivers, harbors, and ports of the United States.

The history of pilotage legislation in Washington State is documented by the Puget Sound Pilots [Ref. 83]:

> The earliest record of pilotage being performed on Puget Sound was documented by the commander of a U. S. Navy expedition, Lt. Charles Wilkes, May 1840. Later, in the 1860s pilotage on Puget Sound was performed by a few sailing ship masters who had settled in Port Townsend. Port Townsend remained pilot headquarters until 1941.
>
> Although the legislative assembly of the Territory of Washington enacted the first law designed to regulate pilotage in January 1863, the first law regulating pilotage on Puget Sound was adopted by the legislative assembly and signed into law in January 1868.
>
> A second law, passed in February 1888, stipulated rules and regulations and provided for gubernatorial appointment of three pilotage Commissioners. By August 1888, eight pilots had been examined and licensed by the Commission. Despite the 1907 repeal of the 1888 law, pilotage services continued to be available to foreign and domestic ship owners calling Puget Sound ports.
>
> Finally, an increase in shipping activity on Puget Sound ultimately led the legislature to declare in 1935 that "...it is the policy of Washington to prevent the loss of human lives, loss of property and vessels, and to protect the marine environment of the state of Washington through the sound application of compulsory pilotage provisions in certain of the state waters" (RCW 88.16.005). As a result, the Washington State Pilotage Act became effective on June 12, 1935. The Act prescribed a five member pilotage commission to administer the Act and to adopt rules and regulations governing pilotage. (The commission was expanded to nine members in 1991.)

Included within the Pilotage Act (under RCW 88.16.180) is the stipulation that any registered oil tanker of 5,000 gross tons or greater take a Washington state licensed pilot while navigating Puget Sound and adjacent waters and be liable for and pay the appropriate pilotage rates.

The escort by tugs of laden oil tankers in Washington State waters is governed by RCW 88.16.190 and WAC 363-116-500. The set of regulations under RCW 88.16.190 first entered force in 1975 and was last amended in 1994. (RCW 88.16.200, which applies to vessels designed to carry liquefied natural or propane gas, requires that such vessels adhere to the provisions of RCW 88.16.190(2) as though they were oil tankers.) The rules have application as described below.

2.1 REVISED CODE OF WASHINGTON 88.16.190

Pursuant to the Revised Code of Washington 88.16.190 (RCW 88.16.190):

(1) Any oil tanker, whether enrolled or registered, of greater than one hundred and twenty-five thousand deadweight tons[1] shall be prohibited from proceeding beyond a point east of a line extending from Discovery Island light south to New Dungeness light.

(2) An oil tanker, whether enrolled or registered, of forty to one hundred and twenty-five thousand deadweight tons may proceed beyond the points enumerated in subsection (1) if such tanker possesses all of the following standard safety features:

   (a) Shaft horsepower in the ratio of one horsepower to each two and one-half deadweight tons; and

   (b) Twin screws; and

   (c) Double bottoms, underneath all oil and liquid cargo compartments; and

   (d) Two radars in working order and operating, one of which must be collision avoidance radar; and

   (e) Such other navigational position location systems as may be prescribed from time to time by the board of pilotage commissioners:

PROVIDED, That, if such forty to one hundred and twenty-five thousand deadweight ton tanker is in ballast or is under escort of a tug or tugs with an aggregate shaft horsepower equivalent to five percent of the deadweight tons of that tanker, subsection (2) of this section shall not apply: PROVIDED FURTHER, That additional tug shaft horsepower equivalencies may be required under certain conditions as established by rule and regulation of the Washington utilities and transportation commission pursuant to chapter 34.05 RCW: PROVIDED FURTHER, That a tanker assigned a deadweight of

1 Although the deadweight limit for Puget Sound is 125,000 tons, the physical vessel size is not constrained. Ships of any size can theoretically enter the Puget Sound but must be either re-load-lined for 125k DWT or if they are commonly entering the subject waters, a Puget Sound mark can be placed below the Load Line plimsoll mark. This Puget Sound mark is not required by federal regulations, IMO Load Lines, nor is it explicitly required by Washington State law. The mark is certified by the U.S. Coast Guard.

less than forty thousand deadweight tons at the time of construction or reconstruction as reported in Lloyd's Register of Ships is not subject to the provisions of RCW 88.16.170 through 88.16.190.

The above requirements, including the selection of 5 percent of the tanker deadweight as the tug horsepower requirement, followed from the 1972 recommendations of the Oceanographic Commission of Washington [Ref. 80], which were presented to the Washington State Legislature. They were codified into RCW 88.16 and enacted into law (through the SHB 527, known as the *Tug Escort Act*) on May 29, 1975.

2.2 WASHINGTON ADMINISTRATIVE CODE 363-116-500

Pursuant to the Washington Administrative Code 363-116-500 (WAC 363-116-500):

(1) RCW 88.16.190(2) requires the escort of a tug or tugs for all oil tankers 40,000 dwt or greater when not in ballast. For purposes of that provision only, deadweight tonnage shall be the maximum summer deadweight tonnage that was assigned to the vessel at the time of construction as reported in Lloyd's Register of Ships. Unless the vessel was structurally altered and remeasured to less than 40,000 dwt, this original deadweight tonnage shall be used for purposes of determining if the vessel requires the appropriate tug escort.

(2) It shall be a violation of this regulation to provide pilotage services to an oil tanker not in compliance with this rule when the pilot has actual knowledge of the noncompliance.

(3) Oil tankers found to be in violation of the provisions of this regulation shall be subject to the provisions of RCW 88.16.150.

(4) The deadweight tonnage provision of this rule is to be used solely for determining the required use of a tug escort.

The current practice for tanker escort is also governed by Federal laws contained in and arising out of the Oil Pollution Act of 1990 (OPA 90). However, the OPA 90 regulations do not require escort of double-hull tankers, and thus these vessels are subject only to RCW 88.16.190.

2.3 OIL POLLUTION ACT OF 1990

Pursuant to the Oil Pollution Act of 1990 (OPA 90) the U.S. Coast Guard published 33 CFR 168, the final rules for escort vessels for certain tankers, on Friday, 19 August 1994. These rules have application as follows:

Vessels: These rules require tug escort for all laden U.S. and foreign flag single-hull tankers in excess of 5,000 gross tons, including tankers with only double bottoms or double sides, or double-hull tankers that do not meet the dimensional standards of 33 CFR 157.10(d) (which are the OPA 90 double hull standards). These rules do not apply to tankers less than 5,000 gross tons or tank barges of any size.

Cargos: These rules apply to tankers carrying petroleum oils that are listed in 46 CFR Table 30.25-1 as pollution category I cargoes oils (MARPOL Annex I). These rules do not apply to non-petroleum (i.e., animal or vegetable) oils or to hazardous chemical cargoes.

Waters: These rules apply to the waters of Prince William Sound from Port Valdez to Hinchinbrook Entrance and the waters of Puget Sound east of a line connecting New Dungeness Light with Discovery Island Light and all points in the Puget Sound area north and south of these lights.

Consistent with the statutory minimums stipulated by OPA 90, the subject rules require a minimum of two escort tugs for affected tanker operations in the applicable waters.

The subject rules set forth performance requirements for escort vessels in two ways:

1) An operational requirement. The tanker must be operated within the performance capabilities of its escorts to reasonably bring it safely under control in the event of a mechanical failure of steering or propulsion, taking into consideration its speed, ambient sea and weather conditions, surrounding vessel traffic, hazards and other factors that may reduce the available sea room.

2) A set of detailed performance requirements for the escort vessel(s). When acting singly or jointly, in any combination as needed, the escort vessel(s) must be capable of:

    a. Towing the tanker at 4 knots in calm conditions, and holding it in a steady position against a 45-knot headwind

    b. Stopping the tanker within the same distance that it could crash-stop itself from a speed of 6 knots using its own propulsion system (this provision has been suspended)

    c. Holding the tanker on a steady course against a 35° locked rudder at a speed of 6 knots

    d. Turning the tanker 90°, assuming a free-swinging rudder and a speed of 6 knots, within the same distance (advance and transfer) that it could turn itself with a hard-over rudder

As explained by the U.S. Coast Guard[2], the first of these performance requirements ('1' above and 33 CFR 168.50(a) of the subject rules) is intended to provide a positive relationship between tanker speed, sea room and environmental conditions, such that, in a generalized sense, increasing tanker speed, decreasing sea room, and worsening

2 At a meeting held in at Coast Guard headquarters in Washington, D.C. on 7 October 1994.

of environmental conditions either individually or together requires increasingly capable tanker escort vessels.

The second of these performance requirements ('2' above and 33 CFR 168.50(b) of the subject rules) is intended to define minimally acceptable escort vessel(s) (i.e., a *'floor'*). The concern motivating this provision was the possibility that some combinations of factors under 33 CFR 168.50(a) (e.g., plentiful sea room, benign environmental conditions and modest tanker speed) might lead to minimum escort vessel capability requirements which corresponded to escort vessels that would be inadequate should transit conditions (e.g., wind and seas) deteriorate unexpectedly.

The performance requirements of paragraph 168.50(b) are not waterway-specific, nor do they require consideration of response time (i.e., the time delays associated with failure recognition, escorts moving into position, passing lines and applying the control forces). The performance requirements are based solely on the towing resistance of the tanker and its self-maneuvering characteristics at 6 knots. The Coast Guard has explained that the navigational limits of the waterway and the time delays for response must be taken into consideration in meeting the operational requirements of paragraph 168.50 (a).

3 TANKER ESCORT: CURRENT PRACTICE AND TRAFFIC INFORMATION

This section provides vessel traffic information, a description of escort tug characteristics, and current tanker escort practices in Washington waters.

3.1 VESSEL TRAFFIC INFORMATION

Tankers, primarily of U.S. registry, with cargo capacity up to 200,000 deadweight tons (dwt) carry approximately 26 million tons of crude oil per year through oil terminals and trans-shipment depots dotting the northwest coast of Canada and the United States. Additionally, about 15,000,000 tons of refined products per year are moved through these same ports. Much of the refined product goes to small coastal communities, and is transported primarily by tug-and-barge vessels, few of which have capacity exceeding 5,000 dwt [Ref. 4].

3.2 ESCORT TUG CHARACTERISTICS

Tugs that are used to escort tankers in Puget Sound are of two types, conventional and tractor tugs. Puget Sound has approximately 15 conventional tugs, 11 Voith Schneider (VSP) type tractor tugs and 2 azimuthing stern drive (ASD) tugs available for tanker escort. Figure 3-1 shows typical outboard profiles.

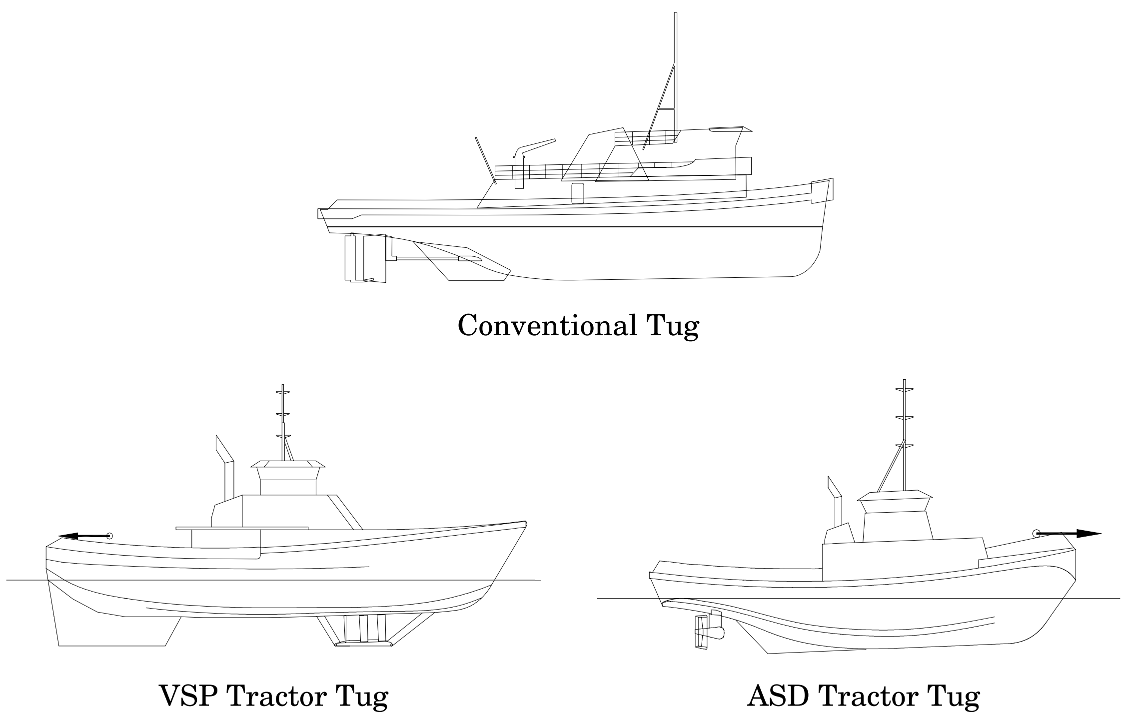


Figure 3-1: Outboard profiles

The conventional and tractor type tugs have different characteristic modes of applying forces in the event of an emergency. Conventional tugs apply corrective forces by pushing on the tanker hull either on the side or on the transom. In braking, a conventional tug will back down on a headline running to the tanker's stern. Tractor tugs primarily apply corrective forces with a line, either by indirect or direct pulling. When using the indirect mode, a tractor tug sets its hull at an angle to direction of motion and thus can develop significant lift and drag forces to augment the power of the propellers. The indirect mode is most effective at higher speeds, generally above 6 knots. The tug will switch to the direct mode for speeds through the water less than 6 knots. Tractor tugs are also capable of pushing directly on the hull. The three primary operating modes of the conventional and tractor tug types are shown in Figure 3-2.

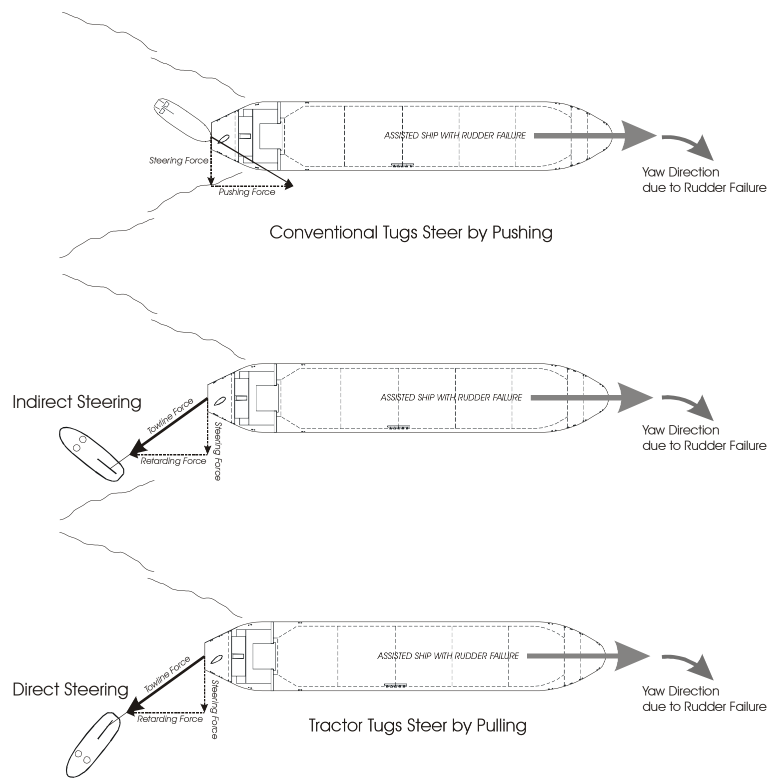


Figure 3-2: Emergency assist modes of Conventional and Tractor Tugs

Emergency response maneuvers to a steering or propulsion failure when the ship is underway are generally some combination of the three primary modes. The maneuvers are defined as follows:

Retard maneuver

a tanker-tug maneuver in which the assisting tug applies maximum braking force to a disabled tanker. In this maneuver, the objective is to take speed off the tanker as quickly as possible by pulling astern. The control of a tanker's turn is not an objective.

Assist maneuver

a tanker-tug maneuver in which the assisting tug applies maximum steering force to a disabled tanker in order to enhance the turn of the tanker. In this maneuver, the objective is to make the turn of the tanker as tight as possible.

Oppose maneuver

a tanker-tug maneuver in which the assisting tug applies maximum steering force to a disabled tanker in order to turn the tanker against its rudder. In this maneuver, the objective is to return the tanker to its original heading by opposing the rudder forces.

The three maneuvers are shown in Figure 3-3.

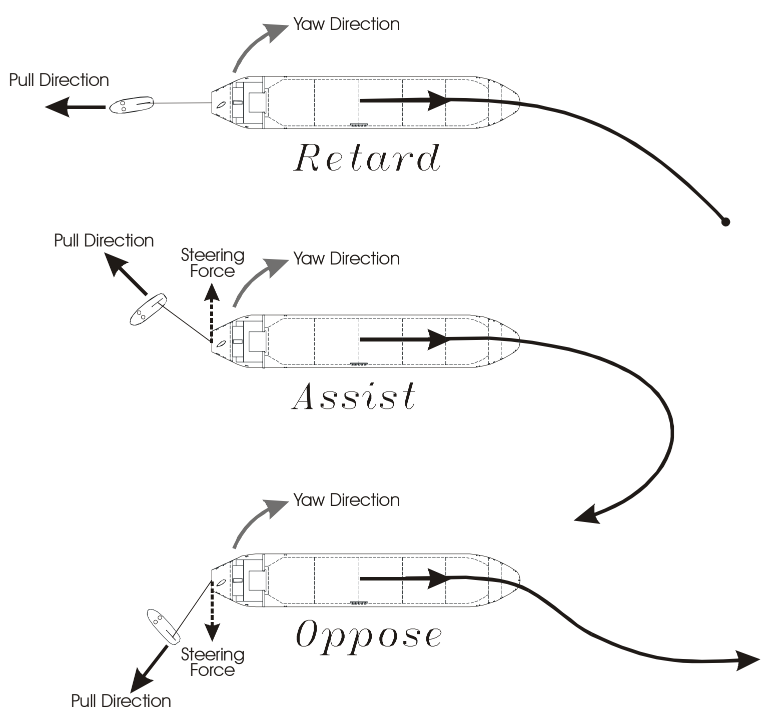


Figure 3-3: Retard, Assist, and Oppose Emergency Maneuvers (showing a tractor tug in indirect mode)

Each tug in the Puget Sound fleet has unique performance capabilities. The performance of a tug in an emergency maneuver depends on its ability to apply corrective forces to the disabled vessel either through a line or through direct contact with the tanker's hull. The forces must be applied while the disabled vessel is still moving at speeds close to its transit speed. Tug capability can be quantified by a pair of speed dependent vector force functions: the maximum braking force together with the associated steering force in case of braking assist; and the maximum steering force together with the associated braking (pushing) force in case of steering assist. The ability to generate forces is a function of the tug's hull type, size, rudders, skeg, horsepower, shafting, propeller size and configuration, stability and freeboard. The performance as a function of speed can be determined from first-principles analysis with verification from full scale testing. An example of performance curves for a 6,250 hp VSP and a conventional tug are shown in the following figures. Figure 3-4 gives the calculated maximum steering and braking capability of a VSP tug. Figure 3-5 shows the same for a twin-screw conventional tug. 3-6 shows a comparison of the maximum steering force capability as a function of speed for the same horsepower conventional and VSP tractor tug.

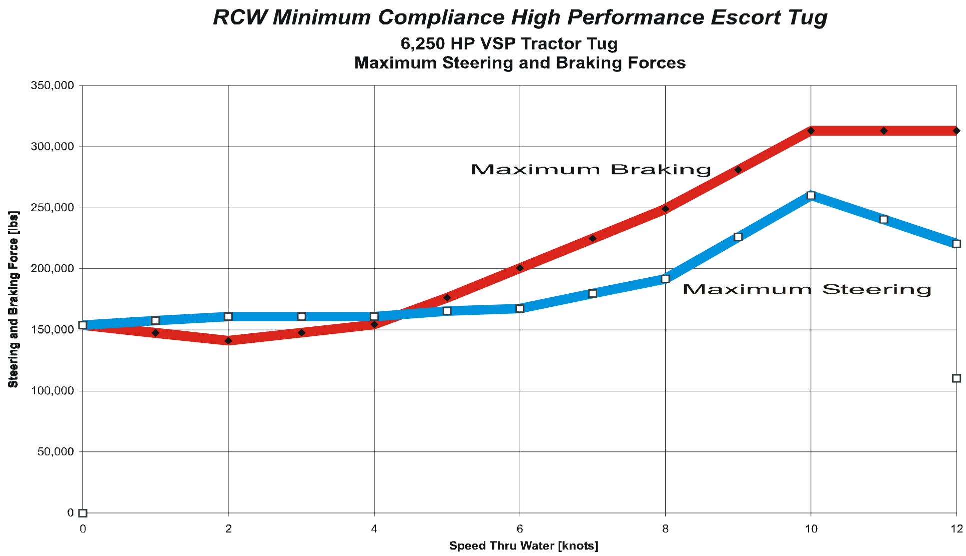


Figure 3-4: Maximum Steering and Braking Forces for a 6,250 hp VSP Tractor Tug

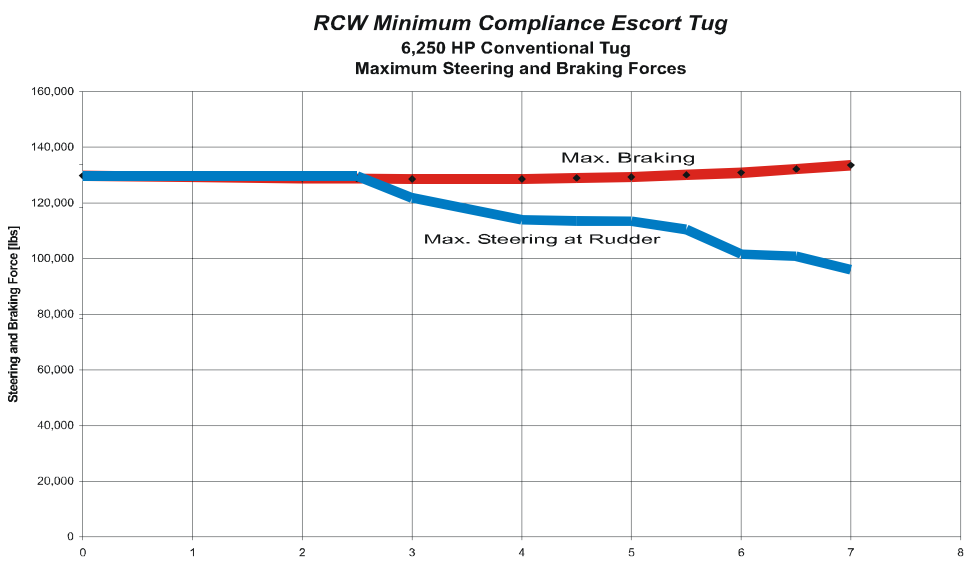
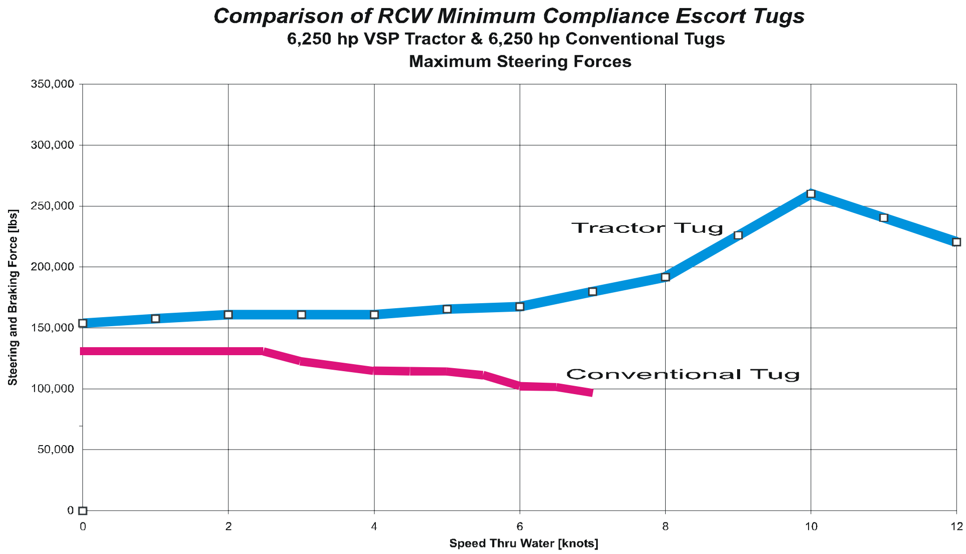


Figure 3-5: Maximum Steering and Braking Forces for a 6,250 hp Conventional Tug



3-6: Maximum Steering Forces for a
6,250 hp VSP Tractor and Conventional Tug

Examples of computer simulations of an oppose maneuver using a conventional and a tractor tug are shown in Figure 3-7. The simulation is of a single-screw double-hull tanker loaded to 125,000 dwt transiting at 10 knots when a hard-over rudder failure occurs. The simulations model an optimum response as described in Section 9. The failure recognition and engine shutdown starts 30 seconds after the onset of the rudder failure.

- The tractor tug is assumed to be tethered and starts applying corrective forces 60 seconds after the onset of the failure and is applying maximum steering forces at 90 seconds.

- The conventional tug is untethered and must maneuver into position on the tanker transom. It begins applying corrective steering forces at 120 seconds and is applying maximum forces at 150 seconds. It does not apply any forces until the speed of the tanker falls below 7 knots.

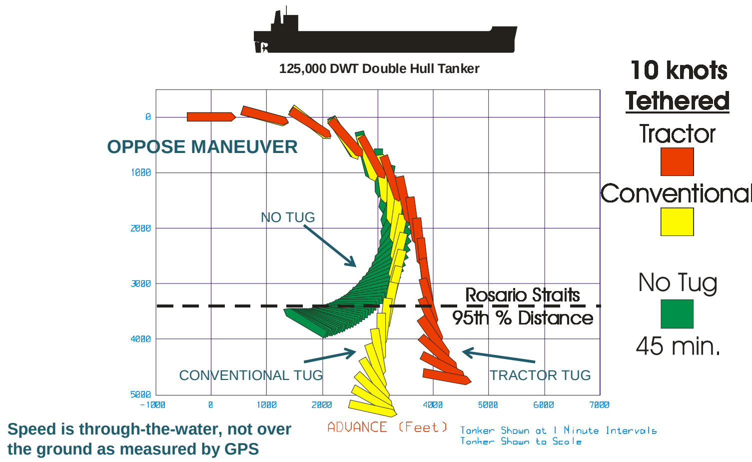


Figure 3-7: Simulation of Oppose Maneuver with 6,250 hp Conventional and 6,250 hp Tractor Tug

Figure 3-8 shows the same tanker and tugs where the response is the *assist maneuver*.

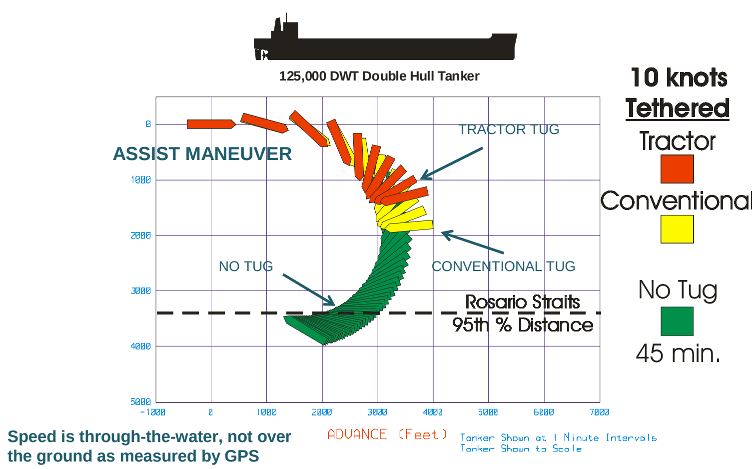


Figure 3-8: Simulation of Assist Maneuver with 6,250 hp Conventional and 6,250 hp Tractor Tug

In the cases shown, the emergency assist maneuver is more effective in reducing off-track transfer distance. However, in general the most effective maneuver is a function of the relative sizes of the tanker and the tug, the speed at which the failure occurs, the magnitude of the failure (e.g., failure rudder angle), the time delays for failure recognition and response, the time delay for applying forces and the wind and wave conditions.

3.3 CURRENT ESCORT PRACTICE

Escort practice has evolved over the last couple of decades, especially in the wake of the *Exxon Valdez* oil spill and the ensuing Oil Pollution Act (OPA 90). The situation is such that today there is heightened awareness of safe-escort issues. The tug companies (Crowley and Foss) also have tanker escort manuals available, to aid shipping companies in the selection of adequately sized tugs.

Further, maritime stakeholders have collaboratively prepared standards of care for tanker escort, representing good industry practice. The standards are contained in the Puget Sound Harbor Safety and Security Committee (PSHSSC) “Harbor Safety Plan”. The PSHSSC is a collaborative organization of public and private maritime organizations. It has as voting members representatives of the following stakeholders: aquaculture, commercial fishing (non-tribal), environmental groups, labor, Native Americans (treaty), passenger-vessel operators, petroleum shippers, pilots, the public, public ports, recreational boaters, the state ferry system, steamship lines, and tug and barge operators. In addition to the stakeholder groups, there are a number of governmental agencies that may serve in a non-voting, advisory capacity.

Escort practice has also come to recognize the performance and safety advantages of tractor tugs over conventional tugs for tanker escort. As described above, two general types of tugs are used to escort tankers in Puget Sound: tractor tugs and conventional tugs. Under Washington State law, the minimum horsepower requirement for escort tugs is 5% of the deadweight tonnage, for example 6,250 hp for the maximum allowable 125,000 dwt. Current practice typically includes one tethered or untethered tractor tug and one untethered conventional tug. However, this system exceeds the regulatory requirements and a single untethered conventional tug of the above-mentioned horsepower is sufficient to satisfy the current state law. (Each setup is subject to the size of the tanker and the availability of tugs.) Recognizing the advantages of tractor tugs over conventional tugs, three of the largest tugs currently operating in Puget Sound (greater than 7,000 hp) are Voith tractor tugs.

A questionnaire was sent to representatives of shipping companies, tug companies and pilots, to gather detailed information and any unique perspectives on current practice. The responses are distilled below.

- <u>Tug selection</u>: This is done by shipping companies, their agents, and the tug companies working together. With tug horsepower requirements determined by the shipping company, the agent approaches the tug company, which then assigns the tug(s). (The selection is based on the requirements of OPA 90 and RCW 88.16.190, tug availability and the best available technology.)

  The role of the agent is to take care of any given ship, its crew and all its needs (such as stores, medical needs, cargoes and owners’ needs), and also to order tugs at appointed times.

  The pilot checks which tug is assigned and whether it is adequate.

- <u>Escort of foreign flag tankers</u>: These tankers fall under the same guidelines as other tankers, and all tanker escorts are performed in the same manner.

- <u>Pre-escort conference</u>: The pre-escort conference takes place via VHF radios in the vicinity of the starting place of the escort. It usually occurs before or at the start of the escort and is between the pilot of the vessel, the master on the bridge, and the tug captains.

The items that are discussed include; weather, visibility, ship draft, shallowest water depth along the transit route, expected traffic conditions, currents, tides, escort route, escort speeds, tug roles, tug capabilities, tug positions, emergency response procedures and VHF radio channels for communications.

The pre-escort conference is considered to be invaluable to the safety of the escort. It helps to ensure that all parties understand their roles in the escort.

Possible emergency response maneuvers are broadly discussed, e.g., tug positioning, lines required. However, details are not generally discussed ahead of time because of location changes. In addition, tugs occasionally change along route and pilots may also be relieved/exchanged. Emergency response details are discussed at the time of an emergency.

Fire fighting is not normally discussed at the pre-escort conference.

- <u>Positioning of tug(s) during an escort</u>: There is not much variability in tug positioning between shipping companies, tug companies and pilots. One tug on either side aft of bridge wing is standard.

  On occasion, the primary tug is positioned running abeam of the tanker or aft of the bridge wing, while the secondary tug moves to where it is wanted, e.g., running ahead for dealing with interference/congestion issues.

  Sometimes, in heavy weather, the tugs will run in the lee of the ship.

- <u>Tethered escorts</u>: Normally, tugs are tethered two to three miles before berthing at any given dock and before transiting narrow channels. This includes most transits of Guemes Channel and through the Saddle Bags into March Point. One shipping company's practice is to have tethered escorts all the way down Puget Sound.

  Tethering is normally done to the stern of the ship (before transiting narrow channels). U.S. tankers have a towing pendant that is hung off the stern (foreign-flag tankers may not have a towing pendant) and may be grabbed by the tug. Alternatively, the tug's line is used: the tug goes to the stern of the ship and sends a messenger line, which is put on a capstan to haul the tug's towline up through a chock. The eye is then dropped on a bitt. In a non-emergency situation, the tethering is usually accomplished in two to ten minutes (typically five).

- <u>Running start</u>: There is a lot of variability on the issue of having a running start, but this seems to be common practice between Buoy 'R' and Davidson Rock. In the open waters of the Straits of Juan de Fuca, the pilots will sometimes ask the tugs to run ahead of the ship (a half mile to two miles) at the start of the escort, since the tankers have the capability of transit faster than most escort tugs. The tankers then meet up with the tugs and reduce speed so as to be alongside the tugs (when nearing Davidson Rock).

- Prevalence of one-tug and three-tug escorts: One-tug escorts are known to happen, especially with the large tugs (*Response*, *Garth*, *Lindsey*, and *Hunter*). They are common when the vessel is double-hull or double-bottomed and the ability and horsepower of the tug meet the minimum standards of the regulations.

  Three-tug escorts are not known to happen. However, occasionally there are three-tug assists. There are instances when one tug is tethered and two escort tugs are "in attendance."

- Role of secondary tug in the event of an emergency: The assumed role for the secondary tug in the event of an emergency is that it would go to the bow and either push on one side or the other, or put a line up in the bow area, as needed. However, this is dependent on the situation, the type of casualty, the traffic in the area, and environmental conditions. Generally, the secondary tug is always told to be ready to act as directed.

  When pushing on side-shell plates, precautions are taken by escort tug captains to push only along framelines or at designated areas of the ship. The weather, sea state, surge, tug weight, and bollard pull are also taken into account.

- Transit speeds during escort: Escort transit speeds are decided by the pilot and master of the vessel, based on the speed and ability of the escort tugs. The transit speeds are monitored by the Vessel Traffic Service system operated by the Coast Guard.

  Generally, the following transit speeds are practiced; between Port Angeles and Davidson Rock: 12 to 14 knots, in Rosario Strait: 10 to 11 knots, in Guemes Channel: 5 to 6 knots, between Cherry Point and March Point: 11 to 12 knots from Cherry Point to Buoy 'C', then down to 8 to 10 knots past Lummi and Viti rocks, and then either 6 knots to Buoy '5' or 4 knots to Saddle Bags. In Puget Sound, transit speeds are such that the speed of the escort tug(s) is not exceeded.

- Transit speed measurements and recording: On the tugs, speeds are measured using GPS and are speeds over ground. Most ships, however, measure speeds through water, using Doppler. Although, ships have the ability to use both GPS and Doppler.

  Tugs do not normally record transit speeds, but escort sheets record the speed at key points. The transit speeds can be reviewed on the electronic navigation systems (ECDIS).

- Tanker escort in Haro Straits: Tanker escorts take place in Haro Straits on occasion, when there is more than one tanker moving in the North Puget Sound system. Sometimes (a few times a year), when there is a conflict with another tanker in Rosario Strait, the tanker will use Haro Straits and will be escorted.

- Issues relating to escort down South Puget Sound (to Tacoma): The long transit down Puget Sound to Tacoma means that human fatigue is a factor. Escorts may be changed several times during the transit, but this can get confusing.

  One shipping company's tanker escort practice is unique in that the tugs are tethered all the way southbound from Point Wilson. This results in the tug companies employing two tug operators and also two pilots on the tanker (to mitigate fatigue). However, the burden on the ship captain remains. Tethered escort is particularly stressful and requires a long, high state of vigilance.

- Issues relating to foul weather: Fog, heavy seas, high winds constitute foul weather. The escort procedures are no different in any weather. However, in very heavy weather, the tug master might radio in and inform the pilot that the escort must slow down if the tug can not keep up with the conditions or to prevent damaging the tugs. (The pilot would also be able to see how the tugs are performing in foul weather.)

  Generally, foul weather reduces the speed of the escort. In limited visibility, the tug would stay aft of the ship and in rough seas may move to the leeward side of the ship.

- Practicing of tug emergency response maneuvers: Tug emergency response maneuvers are seldom practiced, although it is accepted that it would be of benefit to all. There is no set schedule for practicing emergency response maneuvers, but drills are done at random usually at the request of a pilot or master of a vessel. The maneuvering of the tugs is also practiced each time the tug is positioned to assist the ships on or off the berth. However, the maneuvers are not often at full speed or full response; they are seldom at more than 6 knots.

- Escort of tankers other than oil tankers: Escort of tankers other than oil tankers happens only on occasion, especially if the ship has a steering or engine problem. Although, for liquefied-petroleum-gas (LPG) tankers, if the LPG tanker is greater than 40,000 tons DWT, then RCW escort regulations applies to them as well.

- Escort procedures for partially-laden tankers: The escort procedures for partially-laden tankers are the same as for fully-loaded tankers. One issue that comes up, however, is what constitutes ballast (e.g., LPG tankers use butane as ballast, but that is not normal cargo).

- Escort of oil barges: Escort of oil barges does not happen, certainly not on a normal basis. Integrated tug barges, however, are ships and are escorted.

- Communication between tugs and tanker masters and pilots: As previously described, communication between tugs and tanker masters and pilots happens on the same radio channel (via VHF) when under escort. The working channel and back-up channel are decided upon at the pre-escort conference.

It is acknowledged that tugs sometimes serve as additional eyes and ears and have averted accidents and assisted in situations that were not documented. The tugs often check for nets and fish boats and the state of buoys.

- Emergency towing: An escort tug is capable of providing limited slow-speed emergency towing (after the ship starts drifting). This is not usually discussed at the pre-escort conference.

- First-response oil spill containment and clean-up: Escort tugs are not expected to provide first-response oil spill containment and clean-up and have minimal equipment onboard for the purpose. This is not discussed at the pre-escort conference.

- Evolution of escort since OPA 90: Escort practices have evolved considerably since the OPA 90 federal regulations took effect. Tug escort has become standard part of the transit. The quality of ships has improved. Tugs today are also different from before. The pre-escort conference is now second nature. There is a greater awareness of issues today (e.g., the bollard pull of the tug is not to exceed the bitts' strength). Overall systems and communication have improved. There are tug drills and tanker escort manuals. Tug response is faster. Pilots also have been proactive about continuing education including full-mission simulator training. The industry has supported many improvements and provided funding through tariffs.

- Issues relating to double-hull, single-screw tankers and double-hull, twin-screw tankers: Generally, it is not considered that there are any special issues or procedures relating to either double-hull, single-screw tankers or double-hull, twin-screw tankers. ("Tankers are tankers.") However, it is acknowledged that double-hull tankers are larger for a given deadweight and that twin-screw tankers are better than single-screw tankers in terms of maneuvering capability.

3.4 TANKER ESCORT STANDARD OF CARE

The Puget Sound Harbor Safety Plan contains accepted standards and protocols that address environmental and operational elements of maritime operations that are unique to Puget Sound. It serves to "complement and supplement existing and future federal, state, and local law" (PSHSSC 2003). The Harbor Safety Plan is the collaborative work of public and private maritime stakeholders who make up the Puget Sound Harbor Safety and Security Committee (PSHSSC).

The PSHSSC, as of June 2003, has as voting members representatives of the following stakeholders: aquaculture, commercial fishing (non-tribal), environmental groups, labor, Native Americans (treaty), passenger-vessel operators, petroleum shippers, pilots, the public, public ports, recreational boaters, the state ferry system, steamship lines, and tugs and barges. In addition, there are a number of governmental agencies that may serve on the PSHSSC in a non-voting, advisory capacity. These include: local government, the National Oceanic and Atmospheric Administration (NOAA), Pacific States, British Columbia Task Force, U.S. Army Corps of Engineers, U.S.

Coast Guard, U.S. Department of Transportation – MARAD, U.S. Navy, Washington State Department of Ecology and Marine Exchange (administration).

The Harbor Safety Plan (PSHSSC 2003) includes standards of care that formalize and document good industry practice. It addresses heavy weather, movement in restricted visibility, anchoring, equipment failures and equivalent levels of safety, tanker escort, underkeel clearance, lightering, towing vessels, direct-drive diesel plants, bridge team management and plan implementation.

The standard of care for tanker escort is excerpted below.

> APPLICABLE VESSELS: All tank vessels as defined in Federal OPA 90 tanker escort requirements as per 33 CFR 168 (single hull tankers over 5,000 GRT); and State of Washington RCW 88.16.190 and WAC 363-116-500 (all tankers 40,000 DWT and over). Refer to Addendum 1 [below] containing Federal and State tanker escort regulations.
>
> ESCORT OPERATION: All escorts must be in position for timely and effective response. When deemed appropriate by the Master/Pilot to tether, the geographic areas include, but are not limited to, Rosario Strait, Guemes Channel, the Turn Point area of Haro Strait and Boundary Pass, and between Saddlebag and Huckleberry Island.
>
> ESCORT SPEED: A tank vessel that is required to have escort(s) may not exceed the service speed of the escort(s), provided the speed is such that the escort(s) can reasonably be expected to bring the tank vessel under control within the navigational limits of the waterway, given ambient sea and weather conditions, maneuvering and other characteristics of the vessel, surrounding vessel traffic, hazards, and other factors reducing maneuvering room. In Rosario Straits, there is a common practice to limit speed to approximately 11 knots.
>
> TUG SELECTION: Refer to Addendum 2 [below] for an equipment list of particulars for tugboats currently performing tanker escorts in Puget Sound. Equipment list information includes type of tug, LOA, HP, bollard pull (actual or calculated), and whether the tug is outfitted with a strain gauge.
>
> MASTER'S RESPONSIBILITIES: It is the tanker Master's responsibility to ensure the vessel can make a safe transit. Nothing in this S.O.C. precludes the Master from taking the appropriate action to ensure the safety of the vessel. The Master must provide the identification of strong tow point areas where escort tug(s) are likely to be made fast. When vessels tether, particular attention should be paid to not exceed the safe working loads of either vessel's equipment. Tanker Masters and tug Masters should refer to OCIMF guidelines "Recommendation for Ship's Fittings for Use with Tugs".
>
> PRE-ESCORT CONFERENCE: All tank vessels that are required to have escort(s) must also conduct a tanker Master – Pilot – tug Master pre-escort conference as listed in 33 CFR 168.60, and will include relevant port security issues for the transit.
>
> ESCORT MANUALS: Tanker Escort Manuals are available from the tug companies performing escort service in Puget Sound. Tanker owners and operators are encouraged to obtain copies of these manuals for reference.

RECOMMENDATIONS:

TRAINING: When planned, and on a real-time basis, training that is mutually beneficial for the tug and tanker will be conducted within the four scenarios of Hook-up, Retard, Assist, and Deflect. Pilots are encouraged, when doing their 5-year refresher training on manned models, to include scenarios with tethered and non-tethered loss of steerage and propulsion. When conducting simulator training, tanker companies are encouraged to include escort training. Tug companies are encouraged to coordinate with tanker company simulations.

OPERATIONS: Tug companies are encouraged to have one other crew member, besides the boat operator, on the bridge of the escorting tug whenever it is tethered.

S.O.C. REVIEW: During the annual review of the Harbor Safety Plan the continuing evolution of technology onboard escorted tank vessels and their required tugs will be evaluated.

ADDENDUM 1 – Applicable Federal and State Regulations

1. FEDERAL OPA 90 REQUIREMENTS:

TITLE 33 - NAVIGATION AND NAVIGABLE WATERS,
PART 168 - ESCORT REQUIREMENTS FOR CERTAIN TANKERS

168.01	Purpose
168.05	Definitions
168.10	Responsibilities
168.20	Applicable Vessels
168.30	Applicable Cargoes
168.40	Applicable Waters and Number of Escort Vessels
168.50	Performance and Operational Requirements
168.60	Pre-escort Conference

Abstract: All single-hull tankers over 5,000 Gross Tons and laden with petroleum oil cargo are required to be escorted by at least two suitable escort tugs. These requirements apply to any petroleum oil listed in 46 CFR Table 30.25-1 as a pollution category I cargo. These requirements apply to the navigable waters in the U.S. east of a line connecting New Dungeness Light with Discovery Island Light and all points in the Puget Sound area north and south of these lights.

2. STATE OF WASHINGTON REQUIREMENTS:

WAC 363-116-500	Tug Escort Requirements For All Tankers
RCW 88.16.170	Oil Tankers - Intent and Purpose
RCW 88.16.180	Oil Tankers – State Licensed Pilot Required
RCW 88.16.190	Oil Tankers - Restricted Waters - Standard Safety Features Required - Exemptions

Abstract: Tug escort is required for all tankers of 40,000 DWT or greater when in a laden condition. The tug horsepower must equal or exceed 5 percent of the ship's deadweight tonnage. These requirements apply to all liquid cargoes, whether or not petroleum-based. These requirements apply to the navigable waters of Washington State east of a line extending from Discover Island Light south to New Dungeness Light. Laden tankers greater than 125,000 DWT are prohibited from navigating in these regulated waters.

ADDENDUM 2 – Tug Specifications

Vessel Name	Year Built/ Rebuilt	LOA (Feet)	Breadth (Feet)	Draft (Feet)	HP	Propulsion	Bollard Pull	Bollard Pull	Strain Gauge	Method
							Metric Tons	KIPS		
GARTH FOSS	1994	155	46.0	18.5	8,000	Voith Tractor	79	174	Y	A
LINDSEY FOSS	1993	155	46.0	18.5	8,000	Voith Tractor	79	174	Y	A
MARSHALL FOSS	2001	98	40.0	16.0	6,250	Z Drive Tractor	75	165	Y	A
RESPONSE	2002	130	45.7	19.0	7,200	Voith Tractor	70	154	Y	A
INVADER	1974	136	36.5	20.0	7,200	Twin Screw	68	150	N	A
HUNTER	1977	136	36.5	20.0	7,200	Twin Screw	67	147	N	A
BULWARK	1976	136	36.5	20.0	7,200	Twin Screw	65	143	N	C
BARBARA FOSS	1976/1993	126	34.0	14.6	5,400	Twin/Nautican/ HPR	65	143	N	A
GLADIATOR	1975	136	36.5	20.0	7,200	Twin Screw	64	141	N	A
JEFFREY FOSS	1970/1999	120	31.0	14.0	5,400	Twin/Nautican/ HPR	61	135	N	A
PROTECTOR	1996	120	41.5	19.0	5,500	Voith Tractor	55	120	Y	A
FAIRWIND	1975/1990	110	32.1	12.9	4,300	Twin Screw	54	118	N	A
CHIEF	1999	105	36.0	17.0	4,800	Voith Tractor	51	112	Y	A
ANDREW FOSS	1982	107	38.0	14.3	4,000	Voith Tractor	49	108	N	A
ARTHUR FOSS	1982	107	38.0	14.3	4,000	Voith Tractor	49	108	N	A
GUIDE	1998	105	36.0	17.0	4,800	Voith Tractor	49	107	Y	A
SCOUT	1999	105	36.0	17.0	4,800	Voith Tractor	49	108	Y	A
SEA HORSE	1975	126	34.0	17.0	4,860	Twin Screw	48	105	N	A
SEA BREEZE	1976	126	34.0	17.0	4,860	Twin Screw	47	102	N	A
SANDRA FOSS	1976	111.5	31.5	11.6	2,900	Twin/Kort	42	93	N	A
STACEY FOSS	1976	111.5	31.5	11.6	2,900	Twin/Kort	42	93	N	A
DANIEL FOSS	1978/1999	96	32.0	16.9	3,300	Z-Drive Tractor	41	90	N	A
ALAPUL	1970	105	31.1	11.4	3,000	Twin Screw	37	83	N	C
SHELLEY FOSS	1970	90	30.0	14.2	2,400	Twin/Kort	36	79	N	A
WEDELL FOSS	1982	100.2	36.1	11.8	3,000	Voith Tractor	35	76	N	A
HENRY FOSS	1982	100.2	36.1	11.8	3,000	Voith Tractor	35	76	N	A
DREW FOSS	1977	126	34.0	14.6	3,000	Twin Screw	34	75	N	A
SIDNEY FOSS	1976	126	34.0	14.6	3,000	Twin Screw	34	75	N	A

FR = flanking rudder; **HPR** = high performance rudder; **A** = actual bollard pull; **C** = calculated bollard pull

4 ENVIRONMENTAL AND ECONOMIC VALUES PROTECTED

This section discusses the socioeconomic and environmental assets potentially protected by tug escorts and other spill-prevention measures in the San Juan Islands and Rosario Strait region of Puget Sound. The full report was prepared by Environmental Research Consulting under sub-contract to The Glosten Associates, Inc., and is provided in Appendix A.

4.1 OVERVIEW OF SOCIOECONOMIC COSTS OF OIL SPILLS

An oil spill can have serious socioeconomic impacts on the affected region, local communities, residents, the state and the federal government. These impacts include damages to real and personal property, loss of use of natural resources (parks and recreation areas), and loss of income and expenses (fishing, tourism, recreation, shipping and other commerce). As a major shipping port and tourist and recreation area, Puget Sound is particularly vulnerable to socioeconomic impacts from oil spills. Tribal Nations can also be seriously affected, especially regarding subsistence fishing.

The socioeconomic costs are based on the real and perceived impacts, which are related to the degree of oiling, the oil type and persistence, the timing, and the degree to which cleanup response operations can remove oil offshore and onshore and mitigate the damage.

4.2 POTENTIAL SOCIOECONOMIC IMPACTS IN SAN JUAN ISLANDS AND ROSARIO STRAIT

A previous study conducted by Environmental Research Consulting (Contract No. C040018) in conjunction with Applied Science Associates, Inc., investigated the potential costs and impacts of hypothetical 65,000-barrel crude oil spills in the San Juan Islands and Rosario Strait area (south of Lopez Island to Cherry Point and to Point Lawrence). The trajectory, behavior and potential impacts of the spilled oil were modeled using Applied Science Associates, Inc.'s SIMAP software modeling [Refs. 21-22, 27, 31-34].

The socioeconomic impacts of a crude oil spill of 65,000 barrels in the San Juan Islands and Rosario Strait area would depend on the specific trajectory of the oil (based on the unique combination of winds, currents and tides at the time of the spill) and on any effective oil removal operations that would reduce the spreading of the oil and its impact on the shoreline. For the purposes of the current analysis, the *mean* impact is considered – based on 100 simulated runs varying winds, currents and tides. [Socioeconomic impacts based on the 5th, 50th, and 95th percentile shoreline impact[1] are shown in Appendix A.]

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[1] The nth percentile run is that combination of wind, tide and current for which the shoreline oil impact is greater in 100 minus n percent of cases, and the impact is less in n percent of cases, e.g., for the 95th percentile, only 5% of cases had greater impacts and 95% had lesser impacts. Shoreline impacts (square meters of shoreline oiling weighted by shoreline types so that shoreline areas that are more sensitive to damage and more difficult to clean up are weighted more heavily) were used to determine the percentile of the model runs (simulations).

Assuming virtually no effective oil recovery from spill response operations[2], the mean predicted socioeconomic impacts of a 65,000 barrel oil spill in this region based on the SIMAP modeling would be as summarized in Table 4-1.

Table 4-1: Socioeconomic Impacts of 65,000-Barrel Crude Spill in San Juan Islands and Rosario Strait

Socioeconomic Interest		Mean Impact	Standard Deviation
Vessels	Vessel Delay (Operating Deep-Draft Vessels)	$123,661	$52,487
Port	Business Delay	$2,519	$1,066
	Lost Wages	$133,958	$56,675
	Savings to Port[3]	<$307,520>	<$130,105>
Boating	Marinas Lost Income/Damage to Boats	$150,807	$64,100
Commercial Fishing	Commercial Fishing Loss (Value Killed Fish)[4]	$42,727	$60,156
	Commercial Fishing Income Loss (Closures)	$77,620,000	$41,975,000
	Damage to Fishing Gear/Boats	$57,999	$31,367
	Shellfishing Loss (Value Killed Shellfish)	$43,787	$22,303
	Commercial Shellfishing Income Loss (Closures)	$1,988,463	$1,287,612
Tribal Nations	Subsistence Fishing Loss Impacts[5]	$2,229,154	$1,205,000
	Fishing Income Loss	(50% of commercial harvest)	

[2]"No response" means no on-water recovery or dispersion attempted. Protective booming, shoreline cleanup, salvage and spill management/monitoring conducted as required.

[3] Port operators lose some income due to the interest on the delayed business, but save by not having to pay wages and operating costs. Workers suffer losses of wages.

[4] 50% of commercial fishing take goes to tribal nations.

[5] Lost future earning power due to intelligence (IQ) reduction in children dependent on subsistence fishing.

Socioeconomic Interest		Mean Impact	Standard Deviation
Recreation	Recreational Fishing Spending Loss	$459,090	$248,283
	State Parks Lost Use	$1,159,987	$433,075
	State Parks Lost Income	$434,016	$168,398
	National Parks Lost Use	$12,624	$21,891
	National Parks Lost Income	$103,691	$179,804
Recreation (cont'd)	Recreational Boating Lost Use	$1,723	$732
	Recreational Fishing Lost Use	$250	$135
	Wildlife Viewing Spending Loss	$1,894,488	$1,024,571
	Waterfowl Hunting Spending Loss	$169,150	$91,479
	Waterfowl Losses (Future Hunting)	$2,510,160	$1,220,088
Tourism	Tourism Lost Income	$8,179,038	$4,409,658
Lost Oil	Cost of Oil Cargo Lost	$2,249,650	N/A
	Estimated Total Socioeconomic Loss	**$99,259,422**	**$52,473,775**

The *mean* socioeconomic loss for a 65,000-barrel crude oil spill is estimated to about $100 million (or about $1,540 per barrel, $37 per gallon, or $9,700 per cubic meter of crude oil lost). The losses, depending on circumstances of spill trajectory and oil impact, could be twice this amount. With reasonably effective on-water oil spill response, these impacts could be reduced by as much as about 25%.

A 65,000-barrel spill is approximately one-quarter of the largest expected outflow from a double-hulled Suezmax tanker. For comparison, the *Exxon Valdez* oil spill in 1989 was approximately 257,000 barrels. Assuming an approximate linear relationship between spill size and socioeconomic impact, the costs associated with spills of varying sizes that might be expected from outflows from double-hull Suezmax tankers are shown in Figure 4-1 and Table 4-2. The largest mean socioeconomic impact would be $400 million.

It should be noted that there is not always a strict linear relationship between oil spill size and impacts, costs and damages. In general, the more oil spilled and the greater the impact of that oil, the greater the costs. But, some costs are realized regardless of the relative size of the spill (e.g., impacts on tourism due to the perception of damages) and others are directly influenced by the amount of oil that hits a particular area or resource whether due to the specific trajectory of a spill or the actual size of the release from the tanker. Use of a linear (cost per unit spilled) function to estimate costs gives an estimation of potential costs.

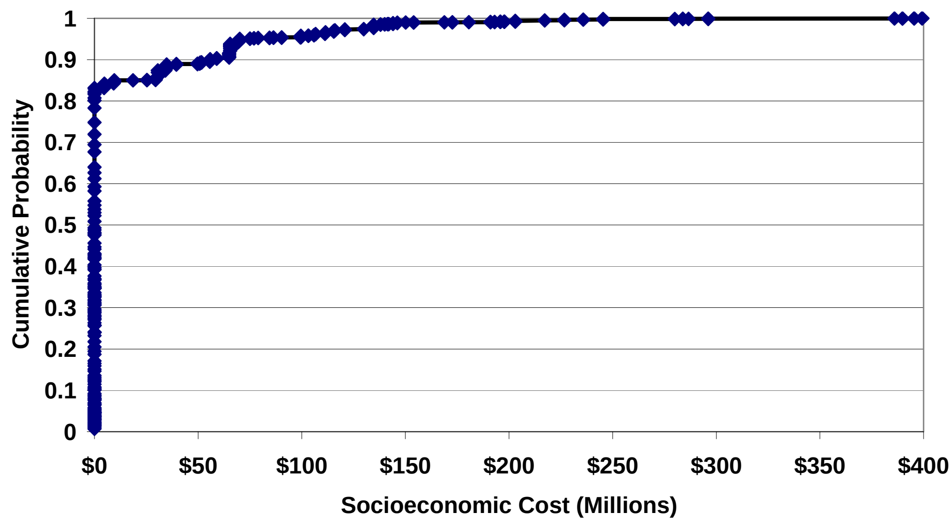

Figure 4-1: Cumulative Probability Distribution Function of Socioeconomic Costs. Data are based on extrapolation from modeling of 65,000-barrel crude tanker spill and the cumulative probability distribution function of outflows.

Table 4-2: Expected Socioeconomic Costs From Crude Tanker Spills Based on Outflow

Outflow Size		Probability of Occurrence (Given Outflow)	Projected Socioeconomic Cost
Cubic Meters	Barrels		
41,172	258,991	0.0000	$399,368,400
30,528	192,036	0.0006	$296,121,600
25,296	159,124	0.0017	$245,371,200
20,926	131,635	0.0075	$202,982,200
17,400	109,454	0.0097	$168,780,000
15,876	99,868	0.0099	$153,997,200
13,390	84,229	0.0262	$129,883,000
10,644	66,956	0.0419	$103,246,800
9,311	58,571	0.0466	$90,316,700
8,144	51,230	0.0475	$78,996,800
7,938	49,934	0.0482	$76,998,600
6,747	42,442	0.0619	$65,445,900
5,322	33,478	0.1066	$51,623,400
5,264	33,113	0.1073	$51,060,800
3,518	22,130	0.1225	$34,124,600
3,041	19,129	0.1490	$29,497,700
1,924	12,103	0.1498	$18,662,800
955	6,007	0.1572	$9,263,500
491	3,089	0.1579	$4,762,700
478	3,007	0.1686	$4,636,600

4.3 POTENTIAL ENVIRONMENTAL IMPACTS IN SAN JUAN ISLANDS AND ROSARIO STRAIT

A crude oil spill in the San Juan Islands and Rosario Strait area could also have a significant impact on wildlife and natural habitats in the area. The SIMAP modeling of the 65,000-barrel crude oil spill in this area included estimations of natural resource damages and wildlife impacts.

Environmental impacts can be measured in two ways: 1) measure of actual wildlife mortality and injuries (with associated reduction in fecundity); and 2) measure of the cost of rehabilitating impacted habitats to increase the likelihood of re-population of oil-damaged areas with wildlife species that were affected. The latter (termed "habitat-equivalency analysis") is generally used in natural resource damage assessment cases handled by the federal government (generally through the National Oceanic and Atmospheric Administration Damage Assessment Center) in conjunction with natural resource trustees at the state and local level. It is considerably more difficult and potentially contentious to put a dollar value on individuals or populations injured or killed from an oil spill. In the analysis conducted for the SIMAP modeling and in the current analysis, the values for habitat equivalency analysis are used to estimate the environmental "costs" of a potential oil spill. Mortality figures for wildlife are also presented to give a sense of the extent of damages that might occur.

Washington State has a damage compensation formula that it uses, generally for smaller spills, to assess natural resource damages for the purpose of seeking compensation from the responsible party for an oil spill. It does not, however, necessarily reflect the degree of damage from a spill, particularly those of larger volumes.

Estimated *mean* mortality figures for a 65,000-barrel crude oil spill in the San Juan Islands and Rosario Strait area is shown in Table 4-3. These results are based on the analyses in French-McCay, *et al.* [Refs. 31-32].

Table 4-3: Environmental Impact of 65,000-Barrel Crude Spill in San Juan Islands/Rosario Strait

Wildlife/Habitat Type	**Mean Impact**	**Standard Deviation**
Shellfish	mortality: 16,461 lbs (7,482 kg)	8,385 lbs (3,811 kg)
Pelagic and Demersal Fish	mortality: 3,561 lbs (1,618 kg)	5,013 lbs (2,269 kg)
Waterfowl	mortality: 29,188 individuals	18,024 individuals
Other Birds	mortality: 3,436 individuals	1,909 individuals
Other Wildlife (Mammals)	mortality: 2 individuals	2 individuals
Wetland Impact	13,100 m^2 oiled	9,670 m^2

Natural resource damages based on re-creation of wetlands would be estimated at a mean of $29.6 million (standard deviation = $21.7 million). This is the equivalent of approximately $455 per barrel ($11 per gallon or $2,667 per cubic meter) of oil spilled. The large standard deviations are indicative of the fact that any one particular spill event might cause inordinate damages to local bird populations based on the trajectory of the spill slick.

Extrapolating a 65,000-barrel spill to spills of other sizes is as problematic as doing this for socioeconomic costs. With wildlife there is likely to be a more direct linear relationship in terms of area of impact and numbers of individuals affected. Direct mortality of individuals, as well as reduced fecundity in affected species, can have longer term population impacts that are not linear.

Using the same methodology as used to estimate the socioeconomic cost of spills of other sizes, the estimated natural resource damages from potential spills from Suezmax tankers are shown in Figure 4-2 and Table 4-4.

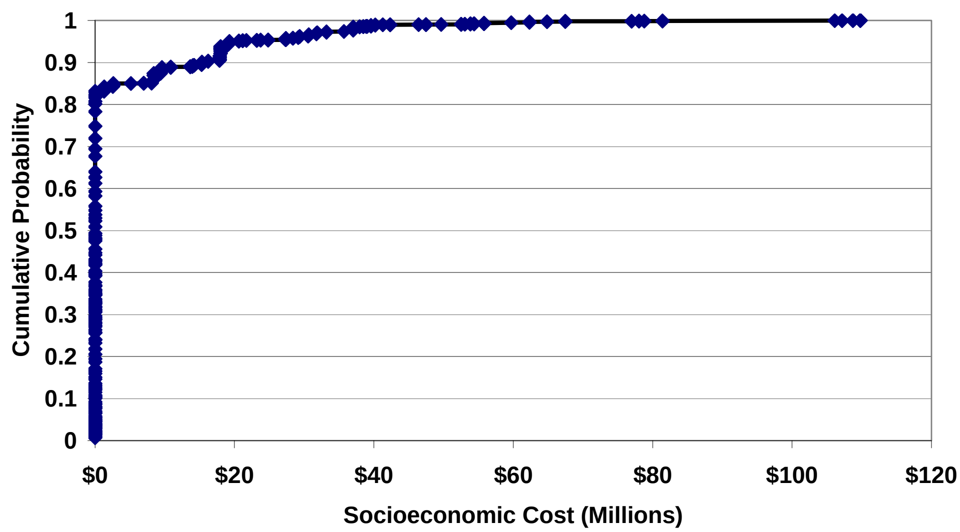

Figure 4-2: Cumulative Probability Distribution Function of Natural Resource Damage Costs (based on extrapolation from modeling of 65,000-barrel crude tanker spill and cumulative probability distribution function of outflows)

Table 4-4: Expected Natural Resource Damage Costs From Crude Tanker Spills Based on Outflow

Outflow Size		Probability of Occurrence (Given Outflow)	Projected Natural Resource Damage Cost
Cubic Meters	**Barrels**		
41,172	258,991	0.0000	$109,805,724
30,528	192,036	0.0006	$81,418,176
25,296	159,124	0.0017	$67,464,432
20,926	131,635	0.0075	$55,809,642
17,400	109,454	0.0097	$46,405,800
15,876	99,868	0.0099	$42,341,292
13,390	84,229	0.0262	$35,711,130
10,644	66,956	0.0419	$28,387,548
9,311	58,571	0.0466	$24,832,437
8,144	51,230	0.0475	$21,720,048
7,938	49,934	0.0482	$21,170,646
6,747	42,442	0.0619	$17,994,249
5,322	33,478	0.1066	$14,193,774
5,264	33,113	0.1073	$14,039,088
3,518	22,130	0.1225	$9,382,506
3,041	19,129	0.1490	$8,110,347

Outflow Size		Probability of Occurrence (Given Outflow)	Projected Natural Resource Damage Cost
Cubic Meters	Barrels		
1,924	12,103	0.1498	$5,131,308
955	6,007	0.1572	$2,546,985
491	3,089	0.1579	$1,309,497
478	3,007	0.1686	$1,274,826

The following figure shows the combination of the projected mean socioeconomic and natural resources costs varying with spill size.

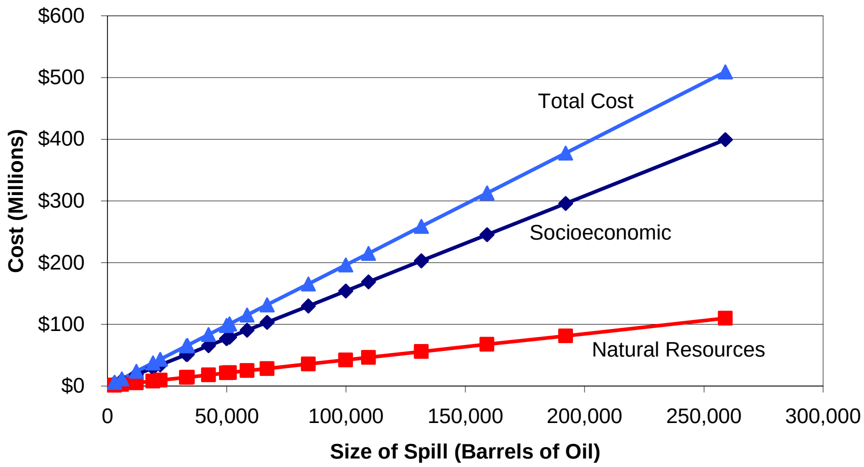

Figure 4-3: Socioeconomic and Natural Resource Costs Protected by Tanker Escorting in San Juan Islands and Rosario Strait

5 PHASE-OUT OF SINGLE-HULL TANKERS

This section describes the phase-out of single-hull tankers as mandated by international and federal regulations. The OPA 90 federal escort laws require escort for single-hull tankers. As these single-hull tankers are phased out, OPA 90 will become obsolete, leaving the Revised Code of Washington (RCW 88.16.190) as the only regulations mandating tanker escort in Washington waters.

5.1 INTERNATIONAL TANKER FLEET

Tankers in international trade are subject to the phase-out requirements of MARPOL Regulations 13G and 13H. The principal requirements of regulations 13G relating to retirement of single-hull double-bottom and double-side tankers are as follows:

- Single hull tankers of 5,000 gross tons (gt) and above cannot operate beyond the anniversary of the date of delivery of the ship in year 2015 or the date on which the ship reaches 25 years of age after the date of delivery, whichever comes earlier.

- Single hull tankers operating beyond 2010 require specific Administration (flag state) approval, and Condition Assessment Scheme (CAS) results must be to the satisfaction of the Administration.

- Double-bottom (double bottom with single side) tankers, double-side (double side with single bottom) tankers, and double-hull tankers that fail to comply with the minimum double hull clearance requirements may continue to operate until the ship reaches 25 years of age after the date of delivery.

The recently adopted MARPOL Regulation 13H bans carriage of heavy grade oil (HGO) on single hull tankers of 5,000 gt and above as of April 5, 2005. Heavy oil is defined as crude oil or fuel oil having a density of 945 kg/m^3 or higher. Single hull tankers carrying crude oil or fuel oil with densities between 900 kg/m^3 and 945 kg/m^3 are subject to CAS and specific administration approval.

Tankers trading in U.S. waters are subject to the double-hull requirements of Section 4115 of OPA 90. International vessels trading to the U.S. must comply with both MARPOL and OPA 90 requirements. The U.S. is not a signatory of MARPOL Regulation 13G or 13H, and therefore U.S. flag vessels trading within U.S. coastal waters are not subject to the provisions of MARPOL 13G and 13H.

OPA 90 calls for the retirement of all single-hull vessels of 5,000 gt and above by 2010 except for those operating under LOOP, which can continue through 2015. Therefore, single-hull vessels permitted under MARPOL to continue operation through 2015 will not be allowed to call U.S. West Coast ports.

Under OPA 90, double-bottom and double-side vessels can operate through 2015, subject to age restrictions. Therefore, double-bottom and double-side vessels permitted by MARPOL to operate beyond 2015 would not be permitted to operate within U.S. waters.

Figure 5-1 compares the single-hull phase-out schedules of OPA 90 and MARPOL, as they apply to the international fleet of tankers greater than 5,000 gt.

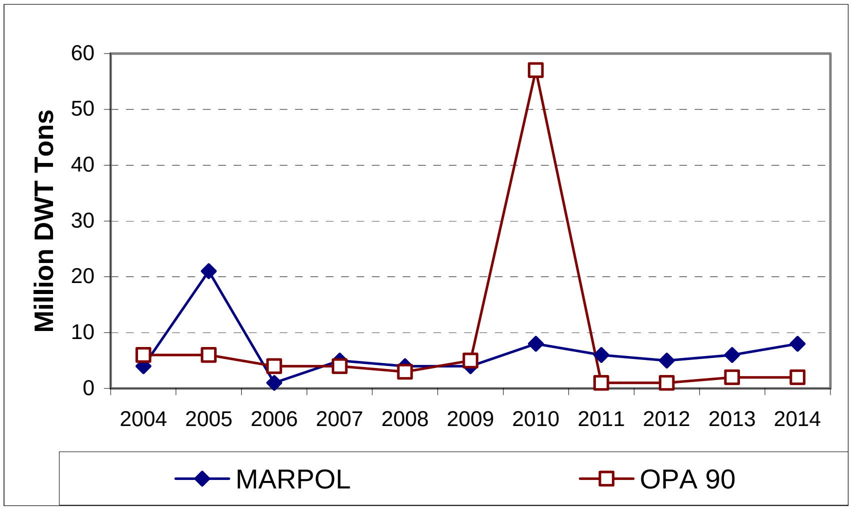

Figure 5-1: Retirement of SH/DB/DS Tankers under MARPOL and OPA 90

The shift in the world fleet from single-hull to double-hull tankers is illustrated in Figure 5-2. According to data maintained by INTERTANKO [Ref. 53], double-hull tankers presently represent about 60% of the world's crude oil ships and account for about 61% of the world's capacity. Thirty-three percent (33%) of the capacity is in single-hull tankers, and about 6% are double-bottom or double-side tankers.

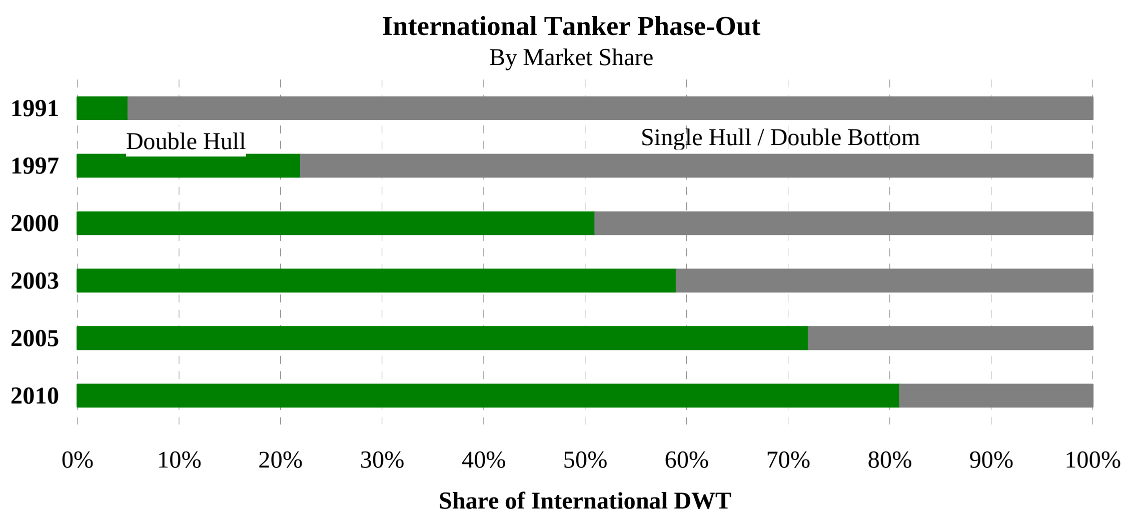

Figure 5-2: Shift from Single- to Double-Hull Tankers in the International Fleet

5.2 U.S. FLAG TANKER FLEET (70,000 dwt and above)

The projected make-up of the U.S. flag tanker fleet, assuming scrapping of tankers, proceeds in accordance with the OPA 90 phase-out schedule is shown in Figure 5-3, Figure 5-4 and Table 5-1. To date, ConocoPhillips has accepted delivery of three *Endeavour Class* tankers under construction at Avondale Shipyard. The remaining two on order will be delivered in late 2004 and 2005. BP has accepted delivery of the first *Alaskan Class* tankers under construction at NASSCO. Three additional vessels will be delivered in 2005 and 2006. Once these deliveries are completed, the U.S. flag fleet will consist of twelve double-hull tankers greater than 70,000 dwt. Of these, eight will be twin screw designs with redundant propulsion and steering systems. It is expected that these eight ships will be deployed in the TAPS trade, moving crude oil from Valdez, Alaska, to the U.S. West Coast.

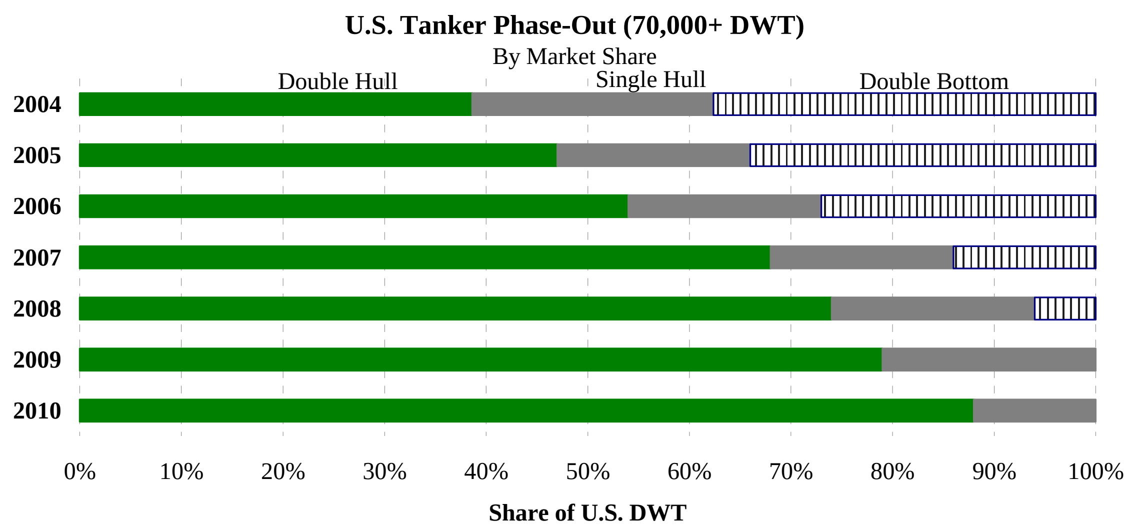

Figure 5-3: Shift from Single- to Double-Hull Tankers in the U.S. Flag Fleet (tankers greater than 70,000 dwt)

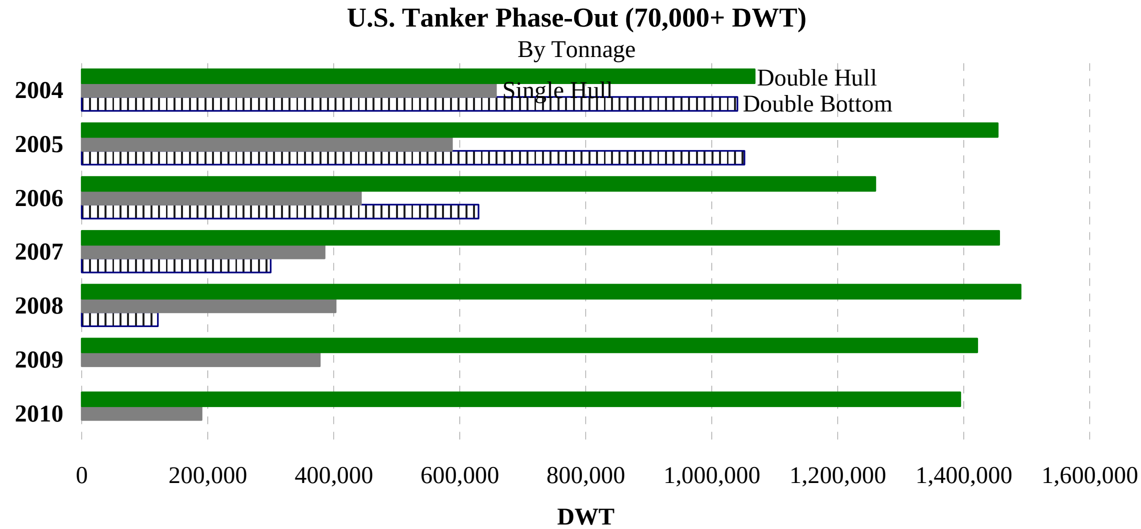

Figure 5-4: Shift from Single- to Double-Hull Tankers in the U.S. Flag Fleet by Deadweight (tankers greater than 70,000 dwt)

Table 5-1: U.S. Flag Tanker Fleet (70,000 dwt and above)

	Double Hull			Single Hull			Double Bottom			Totals	
Year	% DWT	DWT	No.	% DWT	DWT	No.	% DWT	DWT	No.	DWT	No.
2004	38%	1,067,725	8	24%	659,813	4	38%	1,065,601	8	2,793,139	20
2005	47%	1,459,465	11	18%	568,420	3	34%	1,065,601	8	3,093,486	22
2006	54%	1,584,465	12	19%	568,420	3	27%	789,649	5	2,942,534	20
2007	68%	1,584,465	12	18%	429,722	2	14%	318,463	2	2,332,650	16
2008	74%	1,584,465	12	20%	429,722	2	6%	127,003	1	2,141,190	15
2009	79%	1,584,465	12	21%	429,722	2	0%	0	0	2,014,187	14
2010	88%	1,584,465	12	12%	214,862	1	0%	0	0	1,799,327	13
2010	100%	1,584,465	12	0%	0	0	0%	0	0	1,584,465	12

5.3 U.S. FLAG PRODUCT TANKER FLEET (10,000 to 70,000 dwt)

The expected impact of the OPA 90 phase-out requirements on the make-up of the U.S. flag product tanker fleet is shown in Figure 5-5, Figure 5-6 and Table 5-2. This table does not include projections for new construction. The U.S. flag product tankers are primarily deployed in the Atlantic and U.S. Gulf Coast trades. In recent years, tank barge movements in the Pacific region accounted for only about 10% of total U.S. tank barge movements.

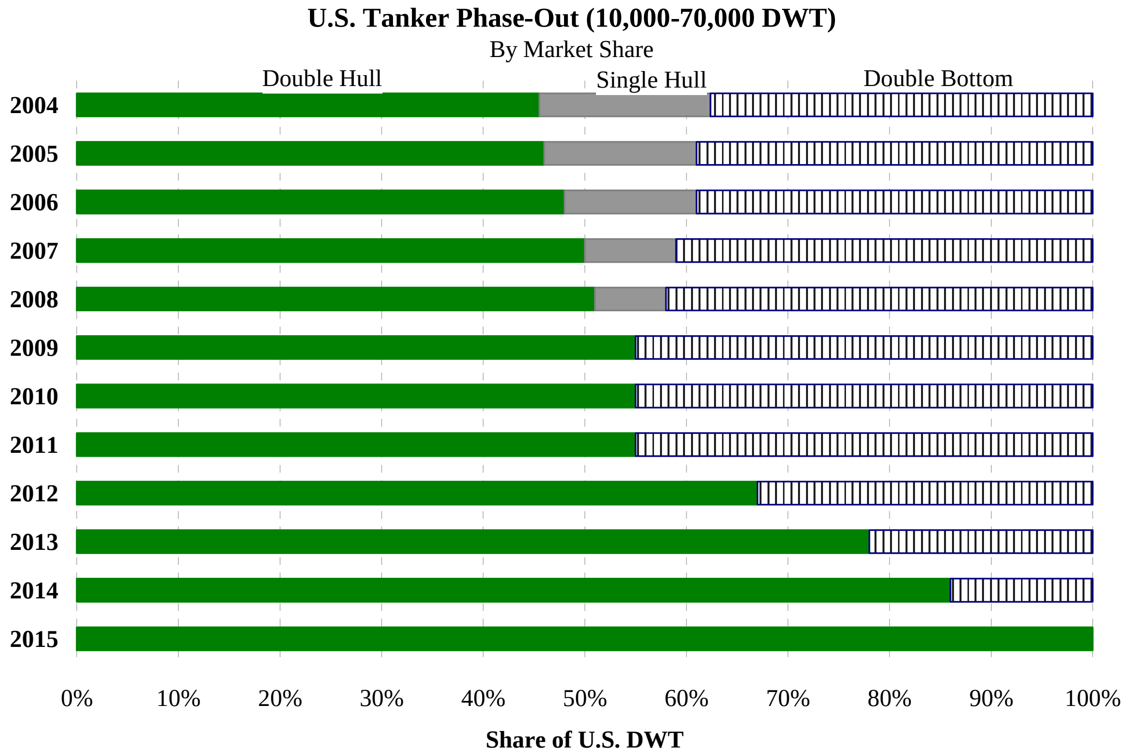

Figure 5-5: Shift from Single- to Double-Hull Tankers in the U.S. Flag Fleet by Market Share

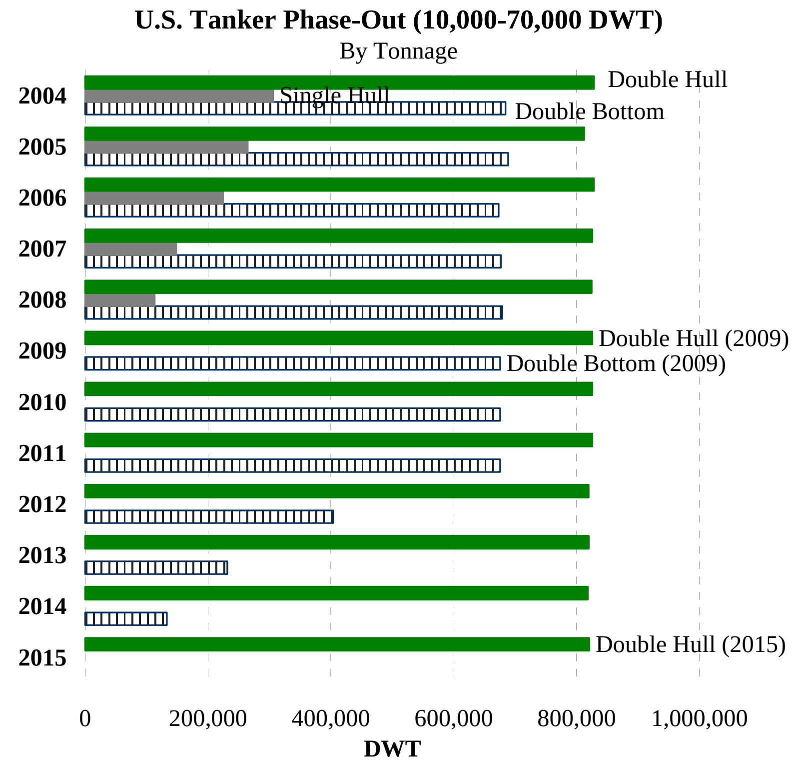

Figure 5-6: Shift from Single- to Double-Hull Tankers in the U.S. Flag Fleet by Deadweight (10,000 - 70,000 dwt)

Table 5-2: U.S. Flag Tanker Fleet (10,000 to 70,000 dwt)

	Double Hull			Single Hull			Double Bottom			Totals	
Year	% DWT	DWT	No.	% DWT	DWT	No.	% DWT	DWT	No.	DWT	No.
2004	46%	820,855	21	17%	299,642	8	38%	680,474	15	1,800,971	44
2005	46%	820,855	21	15%	264,690	7	39%	680,474	15	1,766,019	43
2006	48%	820,855	21	13%	224,684	6	39%	680,474	15	1,726,013	42
2007	50%	820,855	21	9%	150,052	4	41%	680,474	15	1,651,381	40
2008	51%	820,855	21	7%	115,972	3	42%	680,474	15	1,617,301	39
2009	55%	820,855	21	0%	0	0	45%	680,474	15	1,501,329	36
2010	55%	820,855	21	0%	0	0	45%	680,474	15	1,501,329	36
2011	55%	820,855	21	0%	0	0	45%	680,474	15	1,501,329	36
2012	67%	820,855	21	0%	0	0	33%	402,686	9	1,223,541	30
2013	78%	820,855	21	0%	0	0	22%	230,565	5	1,051,420	26
2014	86%	820,855	21	0%	0	0	14%	130,859	3	951,714	24
2015	100%	820,855	21	0%	0	0	0%	0	0	820,855	21
2015	100%	820,855	21	0%	0	0	0%	0	0	820,855	21

5.4 U.S. FLAG TANK BARGE FLEET (10,000 dwt and above)

Currently there are 58 double-hull tank barges of 10,000 dwt or greater, with a combined cargo capacity of about 1.06 million tons. Twenty-two new tank barges with capacity over 10,000 dwt were delivered in 2002-2003, and nineteen barges will be delivered in 2004-2005.

As of 2004, 43% of the large barge fleet had double hulls. The projected availability of single-hull, double-bottom, and double-side barges is shown in Figure 5-7 and Table 5-3.

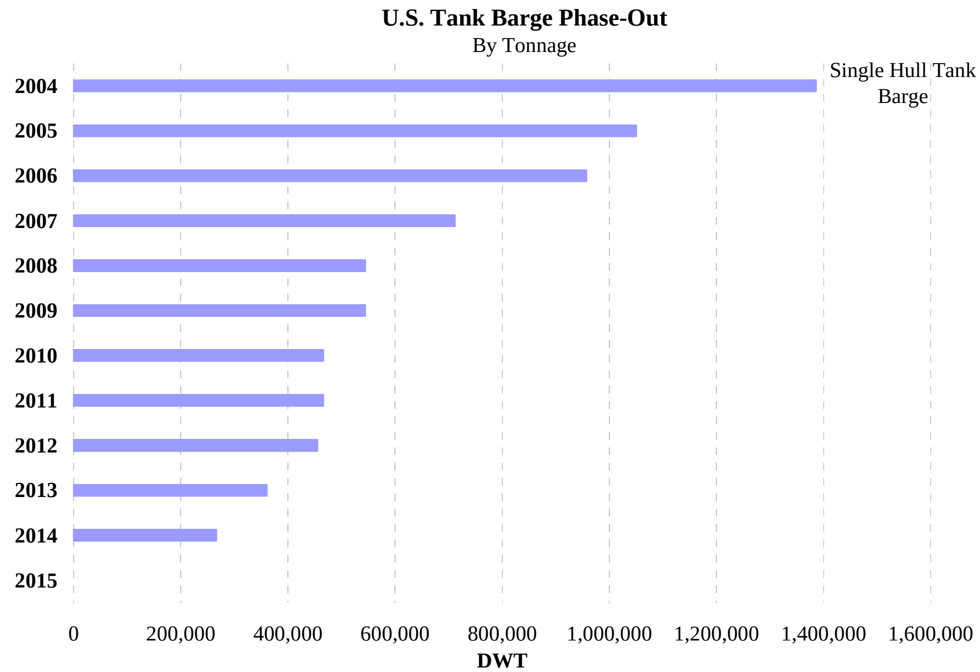

Figure 5-7: U.S. Flag Single-Hull Tank Barges (10,000 dwt and greater)

Table 5-3: U.S. Flag Single Hull Tank Barges (10,000 dwt and greater)

	Single Hull or DB or DS	
Year	**DWT**	**No.**
2004	1,386,243	71
2005	1,050,541	51
2006	957,415	46
2007	711,769	35
2008	544,820	27
2009	544,820	27
2010	466,344	22
2011	466,344	22
2012	455,458	21
2013	360,964	19
2014	266,470	17
2015	0	0

5.5 USE OF ARTICULATED TUG-BARGE VESSELS (ATBs)

Large tank barges compete with product tankers in the 500+ mile coastal changes. The Maritime Administration [Ref. 103] projects that coastal barge traffic will grow at about 2% per annum over the next five years, as large tank barges replace product tankers in these trades. Many of the barges entering the long haul trades will be ATBs, as they generally offer faster speeds than conventional towing arrangements.

According to MARAD statistical data [Ref. 103], nineteen ATBs were delivered in 2002-2003, and eleven more are on order.

Some of the recently delivered ATBs can achieve speeds of over 12 knots. As compared with towed tug-barge units, they offer increased efficiency and lower fuel consumption, greater maneuverability and control, and can effectively operate in more severe sea states. As compared with domestically built double-hull tankers of the same deadweight, ATBs cost less to construct and operate. This is partially because these vessels can be built in the smaller, second tier shipyards that have lower overhead costs, and partially due to the reduced requirements for crew, firefighting equipment, etc. Whereas the ATB may have a crew of eight to ten, the tanker is required to carry a crew of eighteen or more.

With regard to safety and environmental performance, it is reasonable to expect that ATBs with their greater maneuverability and control will outperform towed tug-barge units. Similarly, it is assumed that coastal product tankers with their higher construction standards and crewing requirements will have improved environmental performance as compared to both towed barges and ATBs.

6 CAPABILITIES AND LIMITATIONS OF DOUBLE-HULL, SINGLE-SCREW TANKERS

This section describes and discusses the capabilities and limitations of double-hull, single-screw tankers that presently call in Puget Sound. Additional information on escort tug practice, characteristics and standards can be found in Section 3 of this report.

Currently, single-hull, double-bottom, and double-hull tankers call in Puget Sound. As discussed in Section 5, the single-hull and double-bottom tankers are subject to phase-out under the provisions of OPA90 and MARPOL. Figure 6-1 shows the tank arrangement and midship sections of typical tankers

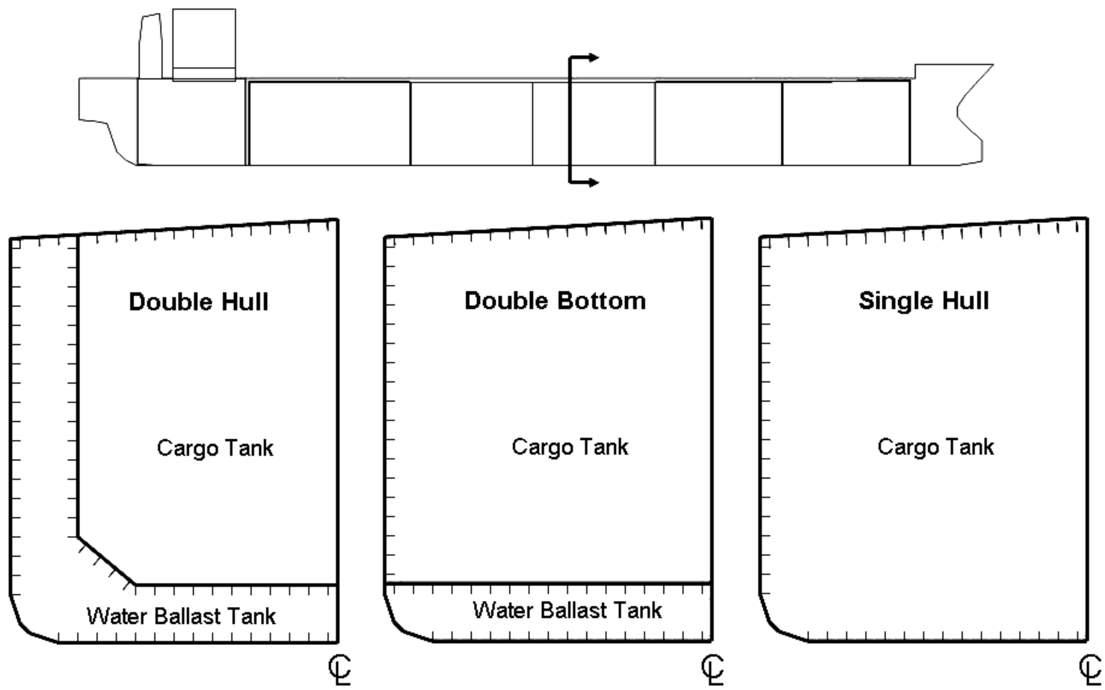

Figure 6-1: Typical Midship Sections of Tankers Entering Puget Sound. (The 5 x 2 – 5 tanks longitudinally and 2 tanks transverse – configuration is shown as an example.)

6.1 U.S. FLAG DOUBLE-HULL, SINGLE-SCREW TANKERS

There are three U.S. flag single-screw, double-hull tankers that are used to move crude oil into the North Puget Sound area: the *Tonsina*, *Kenai*, and *Prince William Sound*. These three vessels are each approximately 125,000 dwt. They have no mandatory retirement date, but are already well beyond the usual 20-year design life for ships of that vintage. Their maintenance costs will continue to increase as they age further, eventually making them economically uncompetitive. At the present level of new construction prices for Jones Act vessels, this may be well into the future.

All three ships are powered by a cross compound steam turbine with twin boilers driving a single reduction gear, and have a single rudder of conventional design. With this configuration, maneuverability at speeds below about 6 kts is limited. Steam turbines provide slightly enhanced maneuverability over diesel engines with solid propellers because they can run at very slow speeds, but they do not enhance steerage capability.

The duplication of boilers provides some level of redundancy since the boiler and its associated fuel delivery system are the least reliable components of the propulsion system. Turbines, gears, shafting and propellers degrade gracefully over time and almost never experience the types of failure that can lead to a serious incident. Normal maintenance intervals are several years, with only minimal inspections required in between. Boilers also degrade gracefully, but can experience total failures if a fitting or boiler tube breaks or corrodes through in either the fuel or the water system. Fuel pumps and air blowers can also fail and disrupt the system unexpectedly. The second boiler provides insurance against these failures and is an improvement over a single diesel propulsion plant.

Rudder or steering gear failures are infrequent but do occasionally occur. Steering gear is usually powered by hydraulic rams or hydraulic turbines; hydraulic pressure is provided by a pump driven by an electric motor. All ships are required to have a backup motor and hydraulic pump to maintain steerage in the event of a failure of these components, but a failure of the rams, piping, rudder post or rudder could render the ship helpless.

These ships have a wing tank width of 2.29 m, and a double-bottom height of 2.77 m. The cargo tanks are arranged 6 x 2 with two slop tanks. This configuration provides a good level of outflow performance, meeting the standards of the new MARPOL Regulation 21, “Accidental Oil Outflow Performance” [Ref. 65].

The heavy fuel oil tanks are in the engine room, located adjacent to the side shell. Because they are situated well above baseline, it is unlikely that a grounding event will penetrate into the fuel tanks. However, they are susceptible to damage from collisions or allisions, such as tug damage and damage when lightering between vessels. Oil outflow analyses [Ref. 65], indicate that in the event of a collision the single-hull bunker tanks are two to four times more likely to be penetrated, and the resulting mean outflow will be two to four times higher than for double-hull bunker tanks. The IMO DE subcommittee [Ref. 51] is currently working on a new regulation for protection of bunker tanks. In its current form, it calls for a double hull or equivalent protection for bunker tanks on vessels greater than 5,000 gt. This legislation is likely to be adopted by 2007.

6.2 FOREIGN FLAG DOUBLE-HULL, SINGLE-SCREW TANKERS

There are currently about 200 double-hull Suezmax tankers in the world fleet, plus approximately one hundred single-hull tankers. The single-hull tankers will be phased out over the next ten years, and will likely be replaced with modern double-hull cargo capacity.

The propulsion plant on the vast majority of these ships consists of a slow speed diesel engine directly coupled to a single fixed pitch propeller. Very few of these ships have bow thrusters.

Wing tank and double-bottom clearances are typically 2.3 to 2.5 meters. This is above the minimum MARPOL requirement of 2.0 meters, as additional clearance is needed for structural and access reasons. The most common cargo tank configuration is 6 x 2 cargo tanks plus two slop tanks. However, there are also a number of 5 x 2 cargo tank configurations, and a few single-tank-across configurations. In particular, the tankers with single-tank-across cargo tank arrangements exhibit poor outflow characteristics.

The majority of the double-hull Suezmax tankers have the bunker tanks arranged within the engine room, adjacent to the sideshell. However, it is expected that most of the future new-builds will have double-side protection for bunker tanks. This is a matter of policy for the major oil companies, and many independent owners are now specifying double sides in way of the fuel tanks. As previously discussed, IMO will likely mandate protection for bunker tanks by 2007.

6.3 REPRESENTATIVE DOUBLE-HULL TANKER DESIGN

The Revised Code of Washington, as noted in Section 2, limits the size of a tanker entering Puget Sound to 125,000 dwt. Principal characteristics of an IMO compliant 125,000 dwt double-hull tanker are given in Table 6-1.

Table 6-1: Principal Characteristics of a 125,000 dwt Tanker Able to Enter Puget Sound

Length overall	266 m
Length between perpendiculars	250 m
Beam (molded)	45.5 m
Depth (molded at side)	22.5 m
Draft (full load)	16.0 m
dwt (full load)	125,000 mt
Draft (normal ballast)	8.0 m
Cargo Tank Arrangement	5 x 2 + 2 slop tanks
Width of double bottom	2.00 m
Width of double side	2.00 m

Although the above tanker has the largest deadweight tonnage permitted to enter Puget Sound, its size does not make it economical for other domestic and foreign trade routes. The current practice is therefore to build a tanker that is of economical size for other trade routes but carries only 125,000 tons of oil when transiting to Puget Sound.

To properly and realistically compare the capabilities and limitations of a baseline double-hull, single propulsion tanker with a typical double-hull, redundant propulsion tanker, such as the *Polar Endeavour* (148,000 dwt) or ATC *Alaska Class* (188,000 dwt) ships, an IMO compliant Suezmax tanker (150,000 dwt maximum) has been chosen in place of the 125,000 dwt Puget Sound tanker. The characteristics and arrangement of this design are provided in Table 6-2 and Figure 6-2.

Table 6-2: Principal Characteristics of Typical Suezmax 150,000 dwt Tanker

Length overall	276.0 m
Length between perpendiculars	260.4 m
Beam (molded)	47.345 m
Depth (molded at side)	23.673 m
Draft (full load)	14.8 m
dwt (full load)	150,000 MT
Draft (normal ballast)	8.5 m
Cargo Tank Arrangement	6 x 2 + 2 slop tanks
Width of double bottom	2.50 m
Width of double side	2.50 m

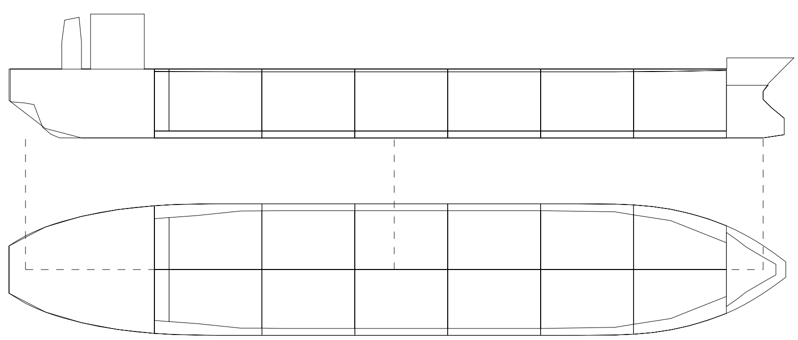

Figure 6-2: Typical Suezmax Tanker Showing the 6 x 2 Cargo Tank Arrangement

The outflow performance of this design will satisfy the new MARPOL Regulation 21 [Ref. 65], and is representative of the configurations of recent Suezmax new-builds. The tanker would have a single propulsion unit utilizing a slow speed diesel engine with a single fixed-pitch propeller and a single rudder.

6.4 MANEUVERING AT LOW SPEEDS

Tankers with steam turbine propulsion systems are able to operate at very low speeds with a high degree of reliability since steam turbines can drive the propellers at any speed from 0 to full speed. Reversing a steam ship's propeller is accomplished by closing one valve and opening another. Steam is admitted to the astern turbine before the propeller stops rotating ahead, which helps to stop the shaft sooner and also enhances the maneuverability.

As noted above, most slow speed diesel propelled ships are fitted with fixed pitch propellers directly connected to the diesel engine. These propulsion engines normally operate at maximum speeds of 85 to 110 RPM, and the ship's speed at that maximum RPM would be between 14 and 16 knots. Slow speed diesel engines cannot operate below about 30% of their full speed. This means that for maneuvering at ship speeds of about 6 knots or less the engine must be repeatedly stopped and restarted in order to provide short bursts of thrust that keep the ship under control. Reversing the propeller on a slow speed diesel ship is accomplished by stopping the engine and restarting the engine in the opposite direction. Each time the engine is restarted, there is the possibility of a failure. Starting these engines is accomplished by high pressure compressed air typically at about 450 psig (30 bar). Ships are required to have a minimum of two starting air receivers to store enough air for at least six starts, and two air compressors to refill the receivers. The number of starts and the time to refill the receivers varies according to classification society rules.

As discussed in Section 7, a limited number of newer tankers have diesel electric power or controllable pitch (CP) propellers. These arrangements enable operation of the propellers at any speed from full astern to full ahead with stepless control of the speed.

As noted in Section 6.3, bow thrusters are not standard equipment on tankers nor are they effective maneuvering devices at high speed. When installed, they can be effective maneuvering devices at speeds below about 4 to 6 knots depending on hull shape. They can be used to initiate a turn and prevent a turn from developing, but can not be used for stopping a turn once it has already begun. Most often they are used when maneuvering for docking and undocking at speeds less than 2 knots.

6.5 ABLE VESSEL CAPABILITIES

Using the typical Suezmax vessel as the baseline vessel, speed and maneuvering characteristics are provided to later show comparison with the redundant-system vessels. It should be noted that each ship may have a different hull shape, propulsion plant, and steering equipment, which all affect the speed and maneuvering characteristics.

The subject ship would be able to obtain a full sea speed of approximately 16 knots. The dead slow ahead speed would be on the order of 2 to 5 knots depending on its loading condition.

The minimum turning diameter and advance must be less than 5.0 and 4.5 times the ship length, respectively, according to IMO Maneuvering Standards. For the subject vessel, this would result in a tactical diameter and an advance distance of 1200 meters. However, the vast majority of ships have much better maneuverability characteristics and are typically in the range of 3.0 for both tactical diameter and advance.

The crash stopping distance of such a tanker starting from 12 knots and 8 knots would be approximately 2 kilometers and 1 kilometer respectively. During a crash stop maneuver, a vessel of this type will have limited steering capabilities and, due to the rotation of the propeller, will normally hook to one direction. This typically results in shorter stopping distances but causes the vessel to fall severely off course.

6.6 DISABLED VESSEL CAPABILITIES WITHOUT ESCORT TUG

When a ship of the above characteristics loses propulsion power, the efficiency and directional steering capabilities of the rudder are greatly reduced. This is exaggerated when vessel speed is low. The ship will gradually reduce speed at a rate proportional to its initial speed squared. For example, the reference ship traveling at 8 knots may take approximately 90 minutes and nearly 9 kilometers to reach 1 knot when a propulsion failure occurs. From this point, the vessel has no steering control and is subject to drift forces of wind, current and waves.

If a steering failure occurs, the rudder can become inoperable at any angle, including the worst case, hard over to port or starboard (approximately 35 degrees). The vessel will turn and continue to do so while the propulsion unit is running. Problem recognition and engine shutdown may take 90 seconds to complete, giving sufficient time for the vessel to run severely off track. Once the engine is shut down and the rudder is inoperable, the vessel will continue on its turning track and eventually slow to a drift, where it is again subject to wind, current, and wave drift forces.

6.7 DISABLED CAPABILITIES WITH ESCORT TUG

A tethered escort tug can have significant impact on the maneuverability and control of a disabled tanker. In the case of engine or rudder failure, three options are presented to control the tanker and keep it from grounding. They are the *retard*, *assist* and *oppose* maneuvers. The maneuvers are more fully explained in Section 3.

Example simulations are shown in the following set of figures. Each figure has several scenarios plotted on the same grid. Simulations are for emergency response maneuvers with a RCW minimum compliance (6,250 hp, conventional) tug and a Suezmax double-hull single-screw tanker loaded to 125,000 dwt. The purpose of the simulations is to show – as a function of speed and failure condition, and if the timing of the response is optimal – that an escort tug response maneuver can be found that will prevent a disabled ship from grounding. These simulations assume calm conditions; e.g. no wind, waves and current. Since in the narrowest points of the waterways the winds and waves are generally aligned with the channel, it can be expected that a maneuver with an escort tug could avert a grounding. However, it is critical that the tanker is transiting at an appropriate speed for the width of the waterway. Again depending on the size of the ship and its load (i.e., displacement), the size of the escort tug (i.e., horsepower) and whether the tug is tethered, speeds around 6 knots are appropriate for the narrower waterways like Guemes Channel; speeds between 10 and 11 knots in Rosario Strait; and up to 12 knots in south Puget Sound and between the line from Discovery Island Light and New Dungeness Light up to Davidson Rock at the south end of Rosario Strait.

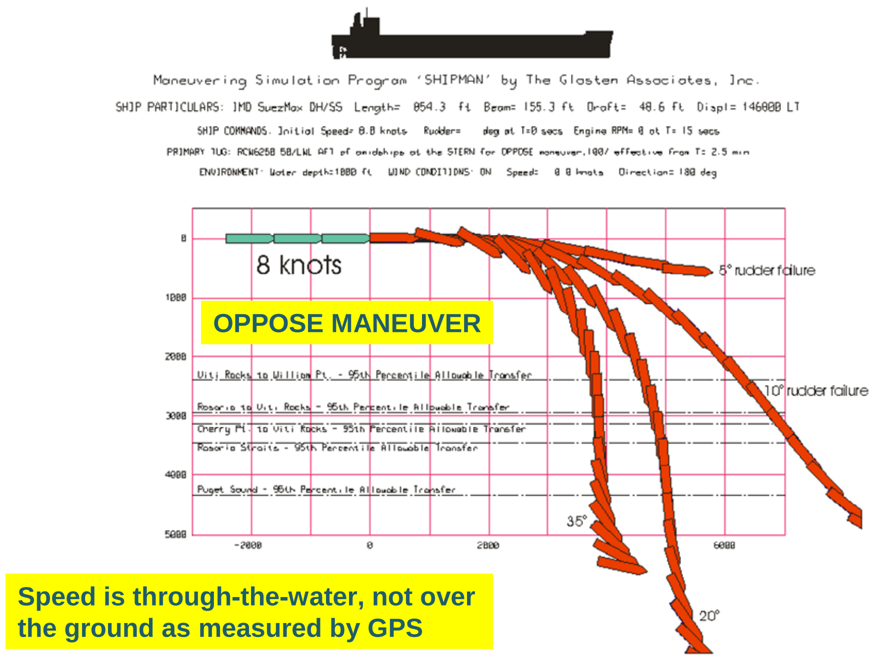

Figure 6-3: Simulation of Oppose Maneuver at 8 knots with Various Rudder Failure Angles – Suezmax Tanker Loaded to 125,000 dwt – RCW Minimum Compliance Escort Tug - Untethered

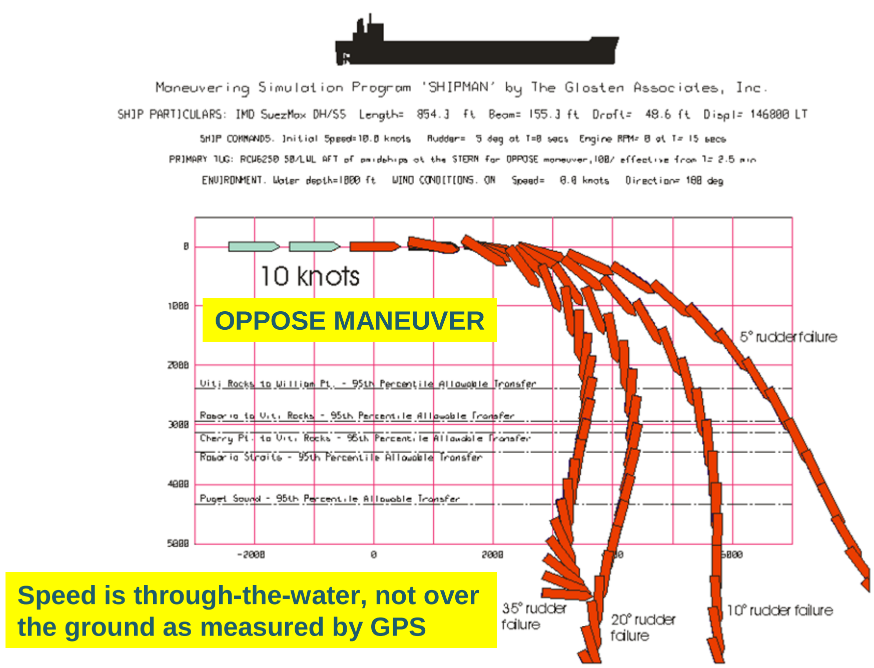

Figure 6-4: Simulation of Oppose Maneuver at 10 knots with Various Rudder Failure Angles – Suezmax Tanker Loaded to 125,000 dwt – RCW Minimum Compliance Escort Tug - Untethered

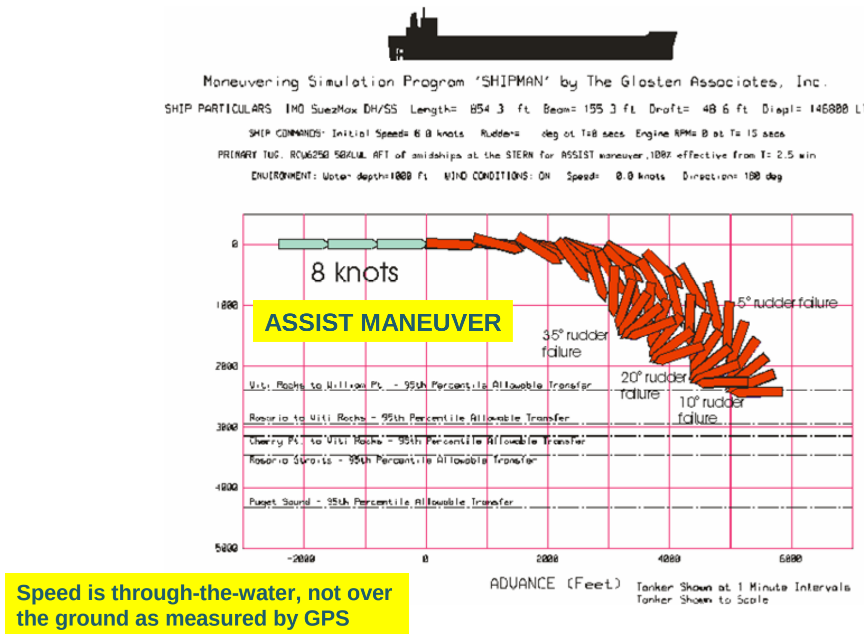

Figure 6-5: Simulation of Assist Maneuver at 8 knots with Various Rudder Failure Angles – Suezmax Tanker Loaded to 125,000 dwt – RCW Minimum Compliance Escort Tug - Untethered

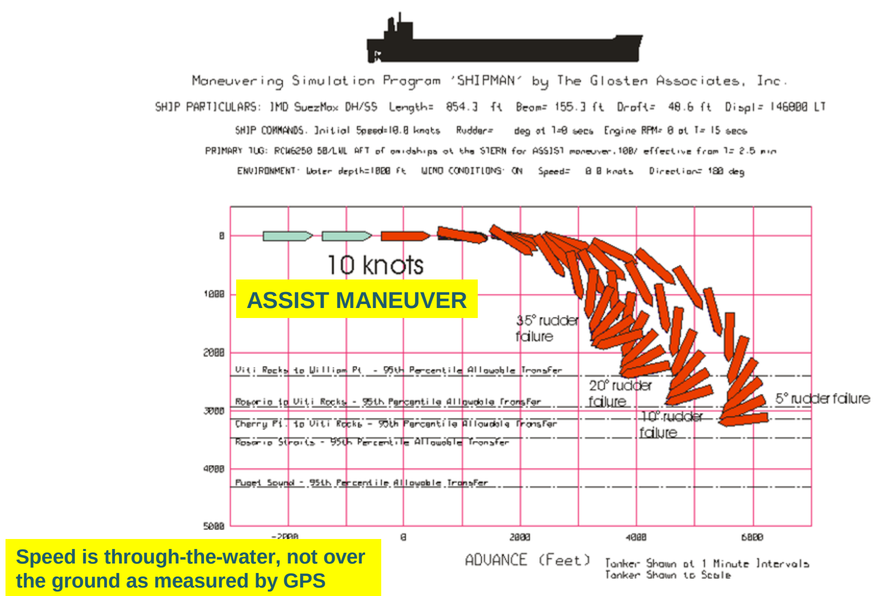

Figure 6-6: Simulation of Assist Maneuver at 10 knots with Various Rudder Failure Angles – Suezmax Tanker Loaded to 125,000 dwt – RCW Minimum Compliance Escort Tug - Untethered

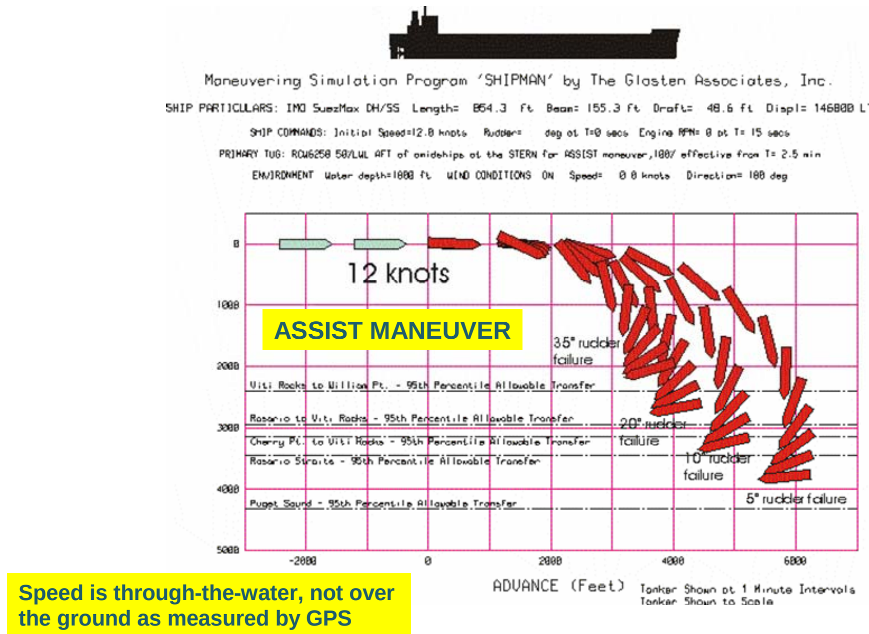

Figure 6-7: Simulation of Assist Maneuver at 12 knots with Various Rudder Failure Angles – Suezmax Tanker Loaded to 125,000 dwt – RCW Minimum Compliance Escort Tug - Untethered

In Tables 6-3 and 6-4 the available channel width is compared to the space required to execute an emergency response maneuver. These tables (6-3 and 6-4) give the off-track transfer distances for the various escort interventions, and indicate whether a properly executed emergency response maneuver (intervention) can be executed within the navigable waters of various waterways. For example, the first line of Table 6-3 deals with the subject tanker transiting at 4 knots. If the rudder fails at 5° relative to the centerline position and the *assist* maneuver is performed, then the tanker's off-track transfer distance is 720 feet. This distance is less than the 95th percentile channel width of Rosario Strait, Guemes Channel, and southern Puget Sound. Therefore, the *assist* maneuver can avert a grounding in all three waterways. The remaining entries in the tables make similar comparisons for various transit speeds, rudder failure angles, and emergency response maneuvers. Table 6-3 compares the off-track transfer distances to the 95th percentile channel widths; Table 6-4 makes comparisons for the 99th percentile channel widths.

Table 6-3: Simulation-Predicted Off-Track Transfer Distances as a Function of Speed, Rudder Angle and Maneuver. Comparisons are made to **95th** percentile channel width.

Tranist Speed at Time of Rudder Failure [knots]	**Rudder Failure Angle** [deg]	Emergency Response **Maneuver**	**Off-Track Distance**	95th Percentile Grounding Averted		
				Rosario Strait	**Guemes Channel**	**Puget Sound** (Admiralty Inlet to Tacoma)
4	5	ASSIST	720'	**YES**	**YES**	**YES**
4	5	OPPOSE	20'	**YES**	**YES**	**YES**
4	10	ASSIST	700'	**YES**	**YES**	**YES**
4	10	OPPOSE	30'	**YES**	**YES**	**YES**
4	20	ASSIST	660'	**YES**	**YES**	**YES**
4	20	OPPOSE	90'	**YES**	**YES**	**YES**
4	35	ASSIST	600'	**YES**	**YES**	**YES**
4	35	OPPOSE	330'	**YES**	**YES**	**YES**
Solution at 4 knots >>>>>>>>>>>>>>>				**YES**	**YES**	**YES**
5	5	ASSIST	1,160'	**YES**	**YES**	**YES**
5	5	OPPOSE	30'	**YES**	**YES**	**YES**
5	10	ASSIST	1,120'	**YES**	**YES**	**YES**
5	10	OPPOSE	90'	**YES**	**YES**	**YES**
5	20	ASSIST	1,010'	**YES**	**YES**	**YES**
5	20	OPPOSE	580'	**YES**	**YES**	**YES**
5	35	ASSIST	860'	**YES**	**YES**	**YES**
5	35	OPPOSE	2,610'	**YES**	NO	**YES**
Solution at 5 knots >>>>>>>>>>>>>>>				**YES**	**YES**	**YES**
6	5	ASSIST	1,620'	**YES**	NO	**YES**
6	5	OPPOSE	70'	**YES**	**YES**	**YES**
6	10	ASSIST	1,530'	**YES**	NO	**YES**
6	10	OPPOSE	370'	**YES**	**YES**	**YES**
6	20	ASSIST	1,350'	**YES**	NO	**YES**
6	20	OPPOSE	3,550'	NO	NO	**YES**
6	35	ASSIST	1,110'	**YES**	**YES**	**YES**
6	35	OPPOSE	4,710'	NO	NO	**YES**
Solution at 6 knots >>>>>>>>>>>>>>>				**YES**	**NO**	**YES**

Tranist Speed at Time of Rudder Failure [knots]	**Rudder Failure Angle** [deg]	Emergency Response **Maneuver**	**Off-Track Distance**	95th Percentile Grounding Averted		
				Rosario Strait	**Guemes Channel**	**Puget Sound** (Admiralty Inlet to Tacoma)
8	5	ASSIST	2,450'	**YES**	NO	**YES**
8	5	OPPOSE	630'	**YES**	**YES**	**YES**
8	10	ASSIST	2,280'	**YES**	NO	**YES**
8	10	OPPOSE	5,580'	NO	NO	NO
8	20	ASSIST	1,940'	**YES**	NO	**YES**
8	20	OPPOSE	7,700'	NO	NO	NO
8	35	ASSIST	1,560'	**YES**	NO	**YES**
8	35	OPPOSE	5,680'	NO	NO	NO
Solution at 8 knots >>>>>>>>>>>>>>>				**YES**	**NO**	**YES**
10	5	ASSIST	3,220'	**YES**	NO	**YES**
10	5	OPPOSE	7,030'	NO	NO	NO
10	10	ASSIST	2,920'	**YES**	NO	**YES**
10	10	OPPOSE	8,940'	NO	NO	NO
10	20	ASSIST	2,420'	**YES**	NO	**YES**
10	20	OPPOSE	8,290'	NO	NO	NO
10	35	ASSIST	1,920'	**YES**	NO	**YES**
10	35	OPPOSE	5,900'	NO	NO	NO
Solution at 10 knots >>>>>>>>>>>>>>>				**YES**	**NO**	**YES**
12	5	ASSIST	3,860'	NO	NO	**YES**
12	5	OPPOSE	9,370'	NO	NO	NO
12	10	ASSIST	3,420'	NO	NO	**YES**
12	10	OPPOSE	9,410'	NO	NO	NO
12	20	ASSIST	2,790'	**YES**	NO	**YES**
12	20	OPPOSE	8,210'	NO	NO	NO
12	35	ASSIST	2,210'	**YES**	NO	**YES**
12	35	OPPOSE	5,940'	NO	NO	NO
Solution at 12 knots >>>>>>>>>>>>>>>				**NO**	**NO**	**YES**

All cases model a Suezmax double-hull single-screw tanker loaded to 125,000 dwt and an untethered RCW minimum compliance 6,250 hp conventional tug, in calm conditions.

Table 6-4: Simulation-Predicted Off-Track Transfer Distances as a Function of Speed, Rudder Angle and Maneuver. Comparisons are made to **99th** percentile channel width.

Tranist Speed at Time of Rudder Failure [knots]	Rudder Failure Angle [deg]	Emergency Response Maneuver	Off-Track Distance	99th Percentile Distance Grounding Averted		
				Rosario Strait	Guemes Channel	Puget Sound (Admiralty Inlet to Tacoma)
4	5	ASSIST	720'	YES	YES	YES
4	5	OPPOSE	20'	YES	YES	YES
4	10	ASSIST	700'	YES	YES	YES
4	10	OPPOSE	30'	YES	YES	YES
4	20	ASSIST	660'	YES	YES	YES
4	20	OPPOSE	90'	YES	YES	YES
4	35	ASSIST	600'	YES	YES	YES
4	35	OPPOSE	330'	YES	YES	YES
Solution at 4 knots >>>>>>>>>>>>>>>				YES	YES	YES
5	5	ASSIST	1,160'	YES	NO	YES
5	5	OPPOSE	30'	YES	YES	YES
5	10	ASSIST	1,120'	YES	NO	YES
5	10	OPPOSE	90'	YES	YES	YES
5	20	ASSIST	1,010'	YES	YES	YES
5	20	OPPOSE	580'	YES	YES	YES
5	35	ASSIST	860'	YES	YES	YES
5	35	OPPOSE	2,610'	NO	NO	YES
Solution at 5 knots >>>>>>>>>>>>>>>				YES	YES	YES
6	5	ASSIST	1,620'	YES	NO	YES
6	5	OPPOSE	70'	YES	YES	YES
6	10	ASSIST	1,530'	YES	NO	YES
6	10	OPPOSE	370'	YES	YES	YES
6	20	ASSIST	1,350'	YES	NO	YES
6	20	OPPOSE	3,550'	NO	NO	YES
6	35	ASSIST	1,110'	YES	NO	YES
6	35	OPPOSE	4,710'	NO	NO	NO
Solution at 6 knots >>>>>>>>>>>>>>>				YES	NO	YES

Tranist Speed at Time of Rudder Failure [knots]	Rudder Failure Angle [deg]	Emergency Response Maneuver	Off-Track Distance	99th Percentile Distance Grounding Averted		
				Rosario Strait	Guemes Channel	Puget Sound (Admiralty Inlet to Tacoma)
8	5	ASSIST	2,450'	YES	NO	YES
8	5	OPPOSE	630'	YES	YES	YES
8	10	ASSIST	2,280'	YES	NO	YES
8	10	OPPOSE	5,580'	NO	NO	NO
8	20	ASSIST	1,940'	YES	NO	YES
8	20	OPPOSE	7,700'	NO	NO	NO
8	35	ASSIST	1,560'	YES	NO	YES
8	35	OPPOSE	5,680'	NO	NO	NO
Solution at 8 knots >>>>>>>>>>>>>>>				YES	NO	YES
10	5	ASSIST	3,220'	NO	NO	YES
10	5	OPPOSE	7,030'	NO	NO	NO
10	10	ASSIST	2,920'	NO	NO	YES
10	10	OPPOSE	8,940'	NO	NO	NO
10	20	ASSIST	2,420'	YES	NO	YES
10	20	OPPOSE	8,290'	NO	NO	NO
10	35	ASSIST	1,920'	YES	NO	YES
10	35	OPPOSE	5,900'	NO	NO	NO
Solution at 10 knots >>>>>>>>>>>>>>>				NO	NO	YES
12	5	ASSIST	3,860'	NO	NO	YES
12	5	OPPOSE	9,370'	NO	NO	NO
12	10	ASSIST	3,420'	NO	NO	YES
12	10	OPPOSE	9,410'	NO	NO	NO
12	20	ASSIST	2,790'	NO	NO	YES
12	20	OPPOSE	8,210'	NO	NO	NO
12	35	ASSIST	2,210'	YES	NO	YES
12	35	OPPOSE	5,940'	NO	NO	NO
Solution at 12 knots >>>>>>>>>>>>>>>				NO	NO	YES

All cases model a Suezmax double-hull single-screw tanker loaded to 125,000 dwt and an untethered RCW minimum compliance 6,250 hp conventional tug, in calm conditions.

7 CAPABILITIES AND EFFECTIVENESS OF DOUBLE-HULL, REDUNDANT-SYSTEM TANKERS

This section describes the double-hull, redundant-system tankers currently in use. The maneuverability (able and disabled) is described, and a comparison is drawn to the double-hull, single-screw ships.

Due to the limited number of existing redundant-system tankers, comparison with an average baseline redundant-system tanker was not possible. Both the *Endeavour* and *Alaska* Class tankers are therefore used as a baseline for comparison to the IMO-compliant Suezmax vessel described in Section 6.

7.1 U.S. FLAG DOUBLE-HULL, REDUNDANT-SYSTEM TANKERS

Two new classes of double-hull tankers with redundant propulsion and steering systems have been designed specifically for the Valdez, Alaska, to U.S. West Coast crude oil trade. Four of the Polar *Endeavour* Class tankers have been delivered by Avondale Shipyard. One additional sister ship is scheduled for delivery in 2005. The first of the *Alaska* Class tankers was delivered by NASSCO in August of this year. Three sister ships are scheduled for delivery by the end of 2006. These are intended to replace existing double-bottom tankers which are subject to phase out under the provisions of OPA 90.

Principal characteristics of the two designs are given in Table 7-1.

Table 7-1: Principal characteristics of the *Endeavour* Class and *Alaska* Class Tankers

	ENDEAVOUR CLASS	*ALASKA* CLASS
Length overall	272.69 m	287.25 m
Length between perpendiculars	258.16 m	274.0 m
Beam (molded)	46.2 m	50.0 m
Depth (molded at side)	25.3 m	28.0 m
Draft (scantling)	17.52 m	18.75 m
dwt (to scantling draft)	140,000 MT	185,000 MT
Draft (normal ballast)	9.5 m	9.5 m
Cargo Capacity	1.0 million bbls	1.3 million bbls
Cargo Tank Arrangement	6 x 2 + 2 slop tanks	6 x 3 + 2 slop tanks
Width of double bottom	3.00 m	2.70 m
Width of double side	3.00 m	2.70 m

Each of these designs has two independent steering systems and engine rooms, with independent shafting and propellers, separated by a boundary which is both watertight and fire resistant. A fire or flood in any one space will not disable the ship. Loss of one steering gear can be compensated by reducing the speed/pitch of one propeller. Loss of one propulsion plant will slow the ship down, but both designs have sufficient power and steering control to turn the vessel in a Beaufort 8 sea condition with one propulsion plant/steering gear disabled.

Each engine room is fitted with all equipment required to make it fully independent of the other. Auxiliary systems such as the fuel oil, lube oil, cooling water and compressed air systems are arranged independently in each engine room. Each engine room has sufficient fuel for 72 hours of continuous operation.

The switchboards in the dual engine rooms are interconnected by bus-tie breakers, providing redundancy and flexibility in operation. In transit, the engine rooms are operated electrically and mechanically as independent entities. The port and starboard engine rooms can be controlled from the starboard machinery control room, and the port engine room can be controlled from the port machinery control room.

In the machinery arrangement of the *Endeavour* Class, each power train consists of the slow-speed diesel engine driving a separately controlled, reversible pitch (CP) propeller. The propeller shaft passes through the tunnel gear without making contact. A combination thrust bearing and remotely operable friction clutch are provided on each shaft. Electrical power in each engine room is provided by a large power takeoff (PTO) and power converter unit (PCU) combination, as well as a ship service diesel generator.

The machinery arrangement in vessels of the *Alaska* Class employs diesel electric propulsion. Four main medium-speed diesel generators, two per engine room, provide the electrical power for all of the ship's needs. Each engine room is fitted with a 10,000-kW, variable speed, reversible, electric motor that drives a fixed pitch propeller.

The reversible, electric propulsion motors on the *Alaska* Class allow the ship to operate the propellers at any speed from full astern to full ahead with step-less control of the speed. The CP propellers on the *Endeavour* Class turn at a constant speed, but by varying the pitch of the propeller blades the thrust developed is infinitely variable from full ahead to full astern. For both of these ship classes, the vessel can go from ahead thrust to astern thrust without stopping and reversing the diesel engines, avoiding the possibility of failure to restart. The ship's speed can be very precisely controlled because the thrust is continuously variable over the full range of operation.

In addition to redundancy, these machinery configurations provide improved maneuvering characteristics at slow speeds. By running one engine ahead and the other astern, it is possible to turn the ship with no forward motion. By doing this with opposite rudder angles, it is possible to crab the ship sideways with no forward motion, without a bow thruster. While it is theoretically possible to perform the same maneuvers with a single-screw ship by alternating ahead and astern thrusts, the single-screw ship can do this only in extremely small amounts under ideal conditions. The twin-screw, twin-rudder configuration can accomplish these maneuvers under normal operating conditions. The twin-screw, twin-rudder arrangement also provides greater control in the event of a crash stop.

Other safety features common to both the *Endeavour* and *Alaska* Class tankers include:

<u>Protection of bunker tanks</u>. Both the *Endeavour* Class and *Alaska* Class tankers have all fuel oil tanks protectively located, with a minimum 2-meter clear double hull. As previously discussed, this exceeds current regulatory requirements, which permit fuel oil tanks arranged outside of the cargo block region to be located adjacent to the shell. It is expected that the new bunker tank protection regulation currently under development at IMO will require minimum clearances of about 1 meter.

<u>Damage stability characteristics</u>. The vessels have double bottoms within the pump rooms. Both vessels have excellent damage stability characteristics. For instance, the *Alaska* Class tanker can withstand raking bottom damage extending from the bow to the pump room.

<u>Cargo and ballast piping</u>. In accordance with current IMO requirements, no ballast piping is routed through cargo tanks, and no cargo or fuel oil piping is routed through ballast tanks. This minimizes the risk of ballast water contamination.

<u>Inerting of ballast tanks</u>. The ballast system and the inert gas system can be cross-connected, allowing emergency inerting of ballast tanks.

<u>Firefighting capability.</u> The pumps and piping systems are arranged such that full firefighting capability is maintained if either machinery room is completely disabled.

<u>Structural design.</u> Both designs have primary hull girder strength well in excess of regulatory requirements. This translates into higher scantlings with more resistance to penetration in the event of a collision or grounding. The structural details are carefully developed, intended to provide a fatigue life of 30 years or more in the severe North Pacific wave environment.

<u>Control and navigation</u>. Both designs are fitted with vessel-wide control systems, with access from the engine control rooms and the bridge. This enables centralized control of key systems, such as machinery, firefighting and cargo systems. The ships are fitted with the latest navigation equipment, including electronic chart display and information systems (ECDIS).

The safety enhancements resulting from the use of escort tugs in the current system include:

1) Tug intervention following a propulsion or steering system failure aboard the escorted tanker.
2) Quick-response emergency towing.

3) Service as advance look-outs and/or auxiliary navigation bridges.
4) Such other emergency services as the escort tugs might be able to provide; e.g., additional firefighting capability and first-order spill response.

Puget Sound tanker escort plans and practices have evolved primarily to serve the first two roles cited above. Accordingly, it is necessary to determine – with respect to maintaining control and safely maneuvering following a propulsion or steering failure – whether the new, double-hull, redundant-system tankers, either with reduced escort or with no tug escort, are as able or more able than single-screw, single-rudder, non-redundant tankers subject to tug escort in accordance with RCW 88.16.190.

7.2 FOREIGN-FLAG, DOUBLE-HULL, REDUNDANT-SYSTEM TANKERS

Since 1995, several vessels on the international market have been built with redundant propulsion and steering systems.

Most recently, the Stena *V-Max* Class (312,000 dwt) has been delivered in 2001, owned by Concordia Maritime of Sweden. This class has DNV RPS notation signifying that it has redundant systems with separation. The two vessels in the class are currently delivering crude oil to Philadelphia refineries on the Delaware River, USA.

The *V-Max* Class is the largest tanker to be produced with redundant systems to date. It has two slow-speed diesel engines routed through clutched reduction gears and, finally, to two fixed-pitch propellers. The reduction gears reduce propeller-induced vibrations and allow the propellers to be disengaged while the engines are still running. This allows additional maneuverability at slow speed, but does not have the flexibility of the controllable-pitch propellers on the Polar *Endeavour* Class tankers.

Vessels of this class also have one of the widest beams (70 meters) of any commercial tanker (58-60 meters is normal for a VLCC). This allows an extremely shallow draft of only 16.76 meters on the laden vessel, and permits the *V-Max* tankers to enter draft-restricted ports [Ref. 49].

Overall, the construction and systems aboard the *V-Max* tankers are very similar to the Polar tankers described in Section 7.1.

There are also plans to build six new redundant-system tankers called the Stena *P-Max* Class (50,000 dwt) that will be delivered in 2005 and 2006 [Ref. 48].

7.3 MANEUVERING AT LOW SPEEDS

The baseline tankers described below are the *Endeavour* Class and *Alaska* Class tankers.

In the Polar *Endeavour* tankers, slow-speed diesel engines are coupled with controllable-pitch propellers. Either propulsion arrangement in the *Endeavour* or

Alaska Class tankers enables operation of the propellers at any speed from full astern to full ahead with stepless control of the propeller (either pitch or rpm) and therefore stepless control of ship speed. Slow ahead speed is approximately 5 to 6 knots, but can be lowered due to the step-less control [Ref. 64].

At slow speeds, bow thrusters (if fitted) are effective and would be used as stated in Section 6.4.

It is important to note that principal characteristics, installed horsepower and conventional shaft/propeller arrangement are similar to the baseline IMO-compliant Suezmax tanker, and therefore maneuvering characteristics are similar at slow speeds. Some additional maneuvering at low speeds is gained by having two independent propulsion and steering systems.

7.4 CAPABILITIES OF ABLE VESSEL

With the Polar *Endeavour* Class vessel as the baseline, speed and maneuvering characteristics are provided to later draw comparison with the single-screw vessels.

The subject ship can obtain a full sea speed of approximately 16 to 18 knots, depending on loading conditions. The slow ahead speed would be around 5 knots, but can be lowered with the controllable pitch propellers.

In reference to Figure 6.3, the minimum turning diameter and advance must be less than 5.0 and 4.5 times the ship length, respectively, according to IMO Maneuvering Standards. For the subject vessel, this would result in a maximum tactical diameter and an advance distance of 1200 meters. The Polar *Endeavour* Class tankers have an approximate tactical diameter and advance distances of 750 to 850 meters at 16 knots speed. This results in tactical diameter and advance distance ratios of 3.0, which easily satisfy the maximum IMO values of 5.0 and 4.5.

The crash stopping distances of the subject ship, starting from 16 knots and 8.5 knots, are approximately 2 and 1.2 kilometers, respectively [Ref. 64]. In theory, having two propulsion systems with counter-rotating propellers would result in straight line crash stopping. However, actual practice and model testing show that the vessel will initiate a turn while attempting a crash stop and therefore fall significantly off track. A redundant-system vessel could sacrifice some of its stopping distance in order to maintain heading or even navigate a curved channel.

7.5 CAPABILITIES OF DISABLED VESSEL

To evaluate the risk of grounding for disabled redundant-system tankers, simulations performed by SSPA Sweden AB for the *Endeavour* Class tankers [Ref. 64] is evaluated to show the off-track distances for various failure scenarios. Based on these data, single failures on redundant-system tankers produce very little offset distance from the centerline of the channel, given that the wind conditions are not above 30 knots and the ship speed is not less than 6 knots.

As noted below in the discussion, typical off-track distances for manual operation and single failures on redundant-system tankers may be two to three times greater than the autopilot controlled distances shown in Figure 7-1 through Figure 7-4 resulting in a possible off-track distance of 75 meters.

Given the 95th percentile width of Guemes Channel (360 meters), it is clear that a redundant-system tanker can avoid grounding in the narrowest of Puget Sound channels, at a beam wind less than 30 knots and ship speed greater than 6 knots.

Figure 7-1 through Figure 7-4 are graphs of the simulation data. These figures show the off-track distance from the center of the channel for various simulations on the tankers. All the below figures represent simulations in the laden design condition through the Valdez Narrows. This location has been chosen from two options as the one most similar to Puget Sound

Although the Valdez Narrows has a turn in the ship channel, the location of failure was considerably before the turn and allowed focusing on only the straight section of the channel. Therefore, off-track distances around the corner are greater than noted in the figures below, but this is to be expected of even an able ship.

It is important to note that no time delays are present between time of failure and corrective action taken. It can therefore be inferred that the ship is operating on autopilot and that manual operation would develop larger offsets. In the opinion of the authors, these offsets would be on the order of two to three times the autopilot controlled operation, given a time delay of ½ to 1 minute for problem recognition and action.

Maneuvering of single-screw vessels with escort tugs provides three tactical options to recover the disabled tanker: retard, assist and oppose. When a redundant-system tanker is without an escort tug, only the oppose maneuver is considered. This is because an assist maneuver results in a very large turning diameter and the retard maneuver results in stopping distances similar to or greater than crash stopping distances.

Using the oppose maneuver exclusively, Figure 7-1 shows that with one propulsion system failure and 45 knots of beam wind, the off-track distance is negligible.

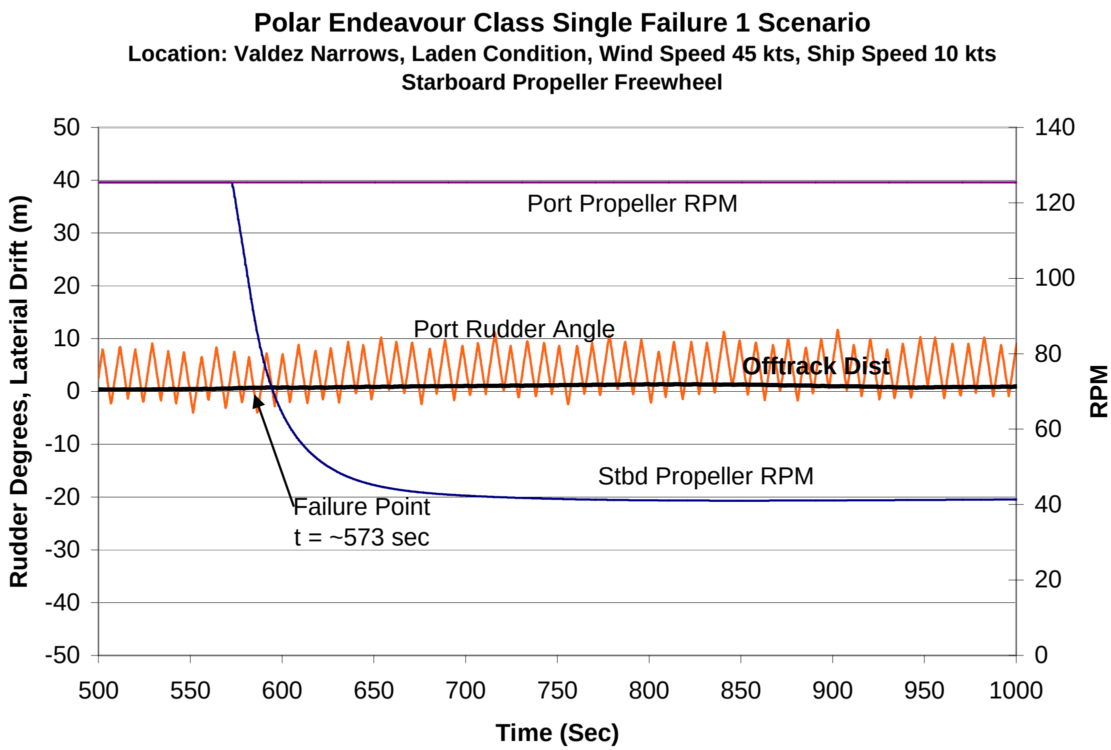

Figure 7-1: Propulsion failure scenario with 45 knots wind speed. The offset distance is negligible.

In Figure 7-2, the port rudder fails at 45 degrees and the port engine is shut down. Under the SSPA simulation definitions, this is a multiple failure scenario. However, the authors view this as a single failure because, when a rudder failure at any significant angle off centerline occurs, the same side propulsion system would be manually shut down and secured to reduce the turning moment created by the failed rudder. *Multiple failure 2 scenario* will therefore be referred to as single rudder failure.

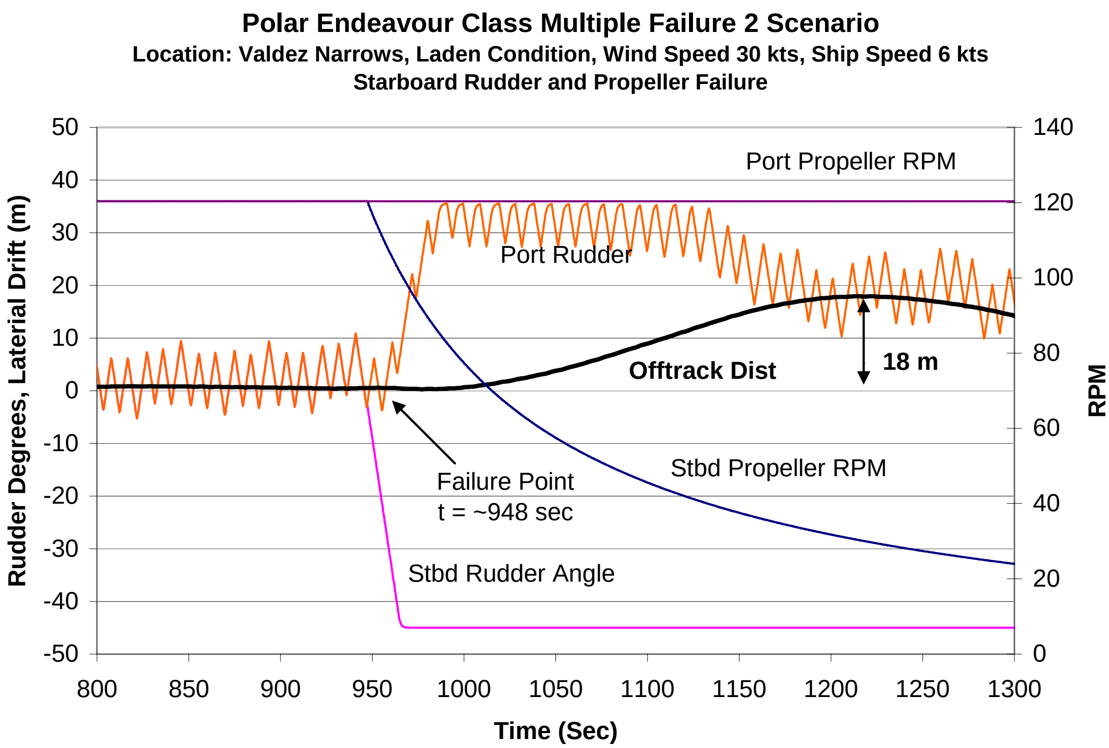

Figure 7-2: Single rudder failure at 45 degrees with 6 knots transiting ship speed 18 meter offset

Figure 7-3 shows decreasing off-track distance with increasing speed for the single rudder failure scenario. This graph shows the relationship of ship momentum to off-track distance and, in general, to maneuvering. A four-knot transiting speed is not shown in the below graph, because with a 30-knot beam wind and a single rudder failure at 45 degrees, the vessel is not able to hold its course.

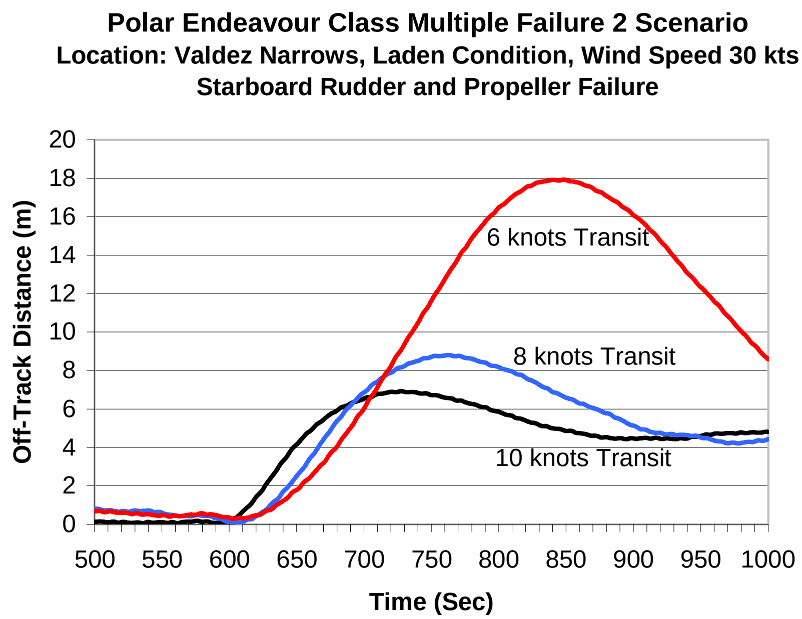

Figure 7-3: Single rudder failure at 45 degrees with 6, 8 and 10 knots transiting ship speed showing the varying off-track distance as a function of ship speed

Figure 7-4 shows that the worst offset (24 meters) where the vessel can return to its original course occurs at a ship speed of 10 knots with 45 knots of wind and a multiple failure of a rudder and associated propulsion unit. At speeds of less than 10 knots, the vessels were not able to maintain course.

With the wind speed set at 30 knots beam on, the ship speed at which the course can be recovered is 6 knots or greater.

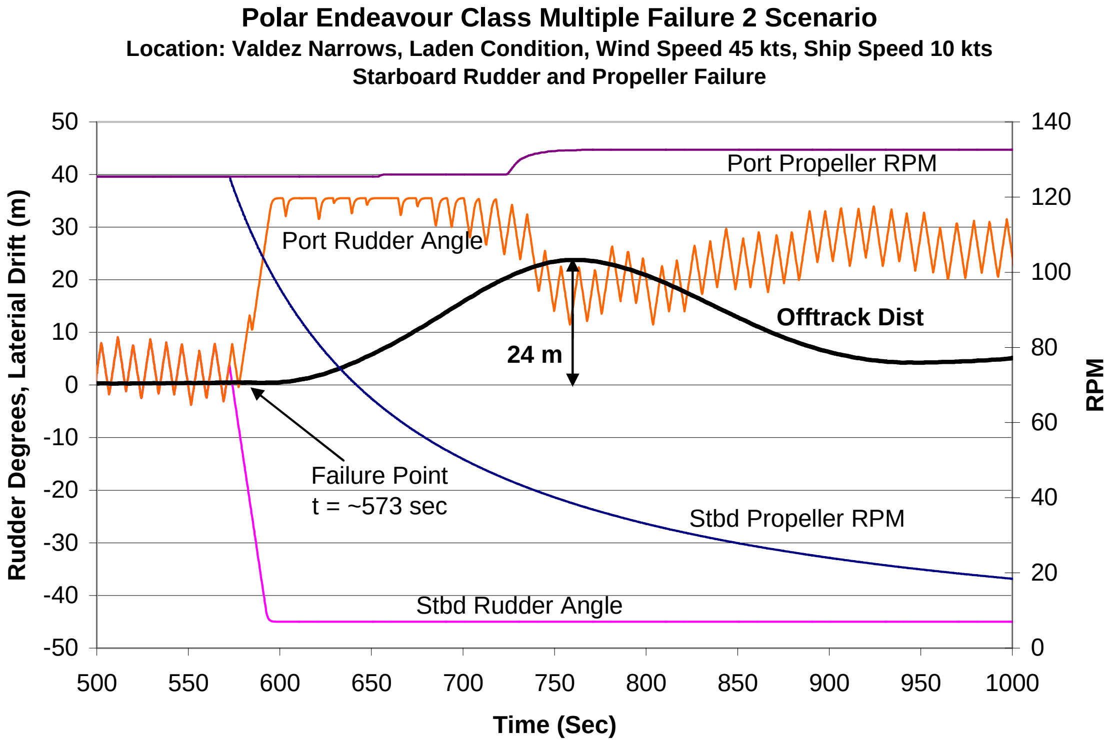

Figure 7-4: Multiple Failure 2 Scenario with 45 knots wind speed. The offset is 24 meters and the vessel recovers.

The authors have assumed that a two system failure with two rudders at 45 degrees or port rudder at 45 degrees and starboard propulsion system failure would result in a grounding.

7.6 COMPARISON OF SINGLE-SCREW AND REDUNDANT-SYSTEM

The mass, size and installed power of the Suezmax baseline double-hull, single-screw tanker and the *Endeavour* Class double-hull, redundant-system tanker are similar. Therefore, slow-speed and able maneuvering characteristics of the two vessels are very similar.

The comparison of the disabled Suezmax baseline double-hull, single-screw tanker having tug escort with the single failure of the *Endeavour* Class double-hull, redundant-system tanker is shown in the following table.

Table 7-2: Comparison of Redundant-System Tanker without Escort to Single-Screw Tanker with Escort when Hard-Over Rudder Failure Occurs

Speed (knots)	Redundant-system tanker without escort† (self correction)	Suezmax single-screw tanker with escort†† (Oppose)	Suezmax single-screw tanker with escort†† (Assist)
6	60'	4,710'	1,110'
8	30'	5,680'	1,560'
10	25'	5,900'	1,920'

†The redundant-system tanker was simulated with a 45° rudder failure in 30-knot beam wind. Propulsion on the same side is voluntarily shut down.

††The Suezmax tanker loaded to 125,000 dwt was simulated with a 35° rudder failure and no wind. Propulsion is voluntarily shut down. Escort for Suezmax tanker is with an untethered 6,250-hp conventional tug.

As can be seen from the simulations shown in Table 7-2, the redundant-system tanker is very successful at maintaining control in the event of a rudder failure. In all cases of one rudder failure, the redundant-system Polar *Endeavour* Class tanker can maintain control and avert a grounding.

The single-screw tanker with escort tug results in significant off-track distance; however, when choosing the appropriate speed for each waterway, the distances are acceptable for the 95th percentile width. There are some waterways in which some rudder failure conditions necessitate speeds of less than 6 knots.

7.7 REDUNDANT SYSTEM DEFINITION

As the concept of redundancy in tanker propulsion and steering systems is relatively new, different definitions exist. Three definitions are presented here; two are from classification societies (American Bureau of Shipping and Det Norske Veritas) and one is a regulatory definition (California Code of Regulations).

7.7.1 ABS Redundant Propulsion Notation

American Bureau of Shipping (ABS) has developed rules for classing redundant propulsion machines and systems in ships. Various notations are assigned based on the specific arrangement of the propulsion system(s) and associated auxiliary systems.

ABS has the following class notations given in Part 4, Chapter 3, Section 6 of ABS *Rules for Building and Classing Steel Vessels*, 2005 [Ref. 3].

- **R1:** A vessel fitted with multiple propulsion machines but only a single propulsor and steering system will be assigned the class notation.

- **R2:** A vessel fitted with multiple propulsion machines and also multiple propulsors and steering systems (hence, multiple propulsion systems) will be assigned the class notation.
- **R1-S:** A vessel fitted with only a single propulsor but having the propulsion machines arranged in separate spaces such that a fire or flood in one space would not affect the propulsion machine(s) in the other space(s) will be assigned the class notation.
- **R2-S:** A vessel fitted with multiple propulsors (hence, multiple propulsion systems) and having the propulsion machines and propulsors, and associated steering systems arranged in separate spaces (propulsion machinery space and steering gear flat) such that a fire or flood in one space would not affect the propulsion machine(s) and propulsor(s), and associated steering systems in the other space(s) will be assigned the class notation.

The basic performance requirements for a redundant notation are to perform the following upon a single failure:

- Continuously maintain or restore the propulsion and steering system(s) within two minutes of failure
- Maintain a speed of one half design speed or seven knots, whichever is less
- Possess adequate steering capabilities at the above speed
- Continue operation at the above conditions for at least 36 hours

In addition, the mark **+** affixed to the end of any of the above class notations (e.g., **R1+**, **R2-S+)** denotes that the vessel's propulsion capability is such that, upon a single failure, propulsive power can be maintained or immediately restored to the extent necessary to withstand adverse weather conditions without drifting. The lack of the mark + after the class notation indicates that the vessel is not intended to withstand adverse weather conditions, but can maintain course and maneuverability at a reduced speed under normal expected weather conditions.

Example arrangements for each of the above notations are shown in Figure 7-5. The *Endeavour* Class ships were the first vessels certified by ABS with the **R2-S+** notation. The ATC *Alaska* Class vessels are functionally capable of meeting the **R2-S+** notation but the owners have chosen not to pursue this notation.

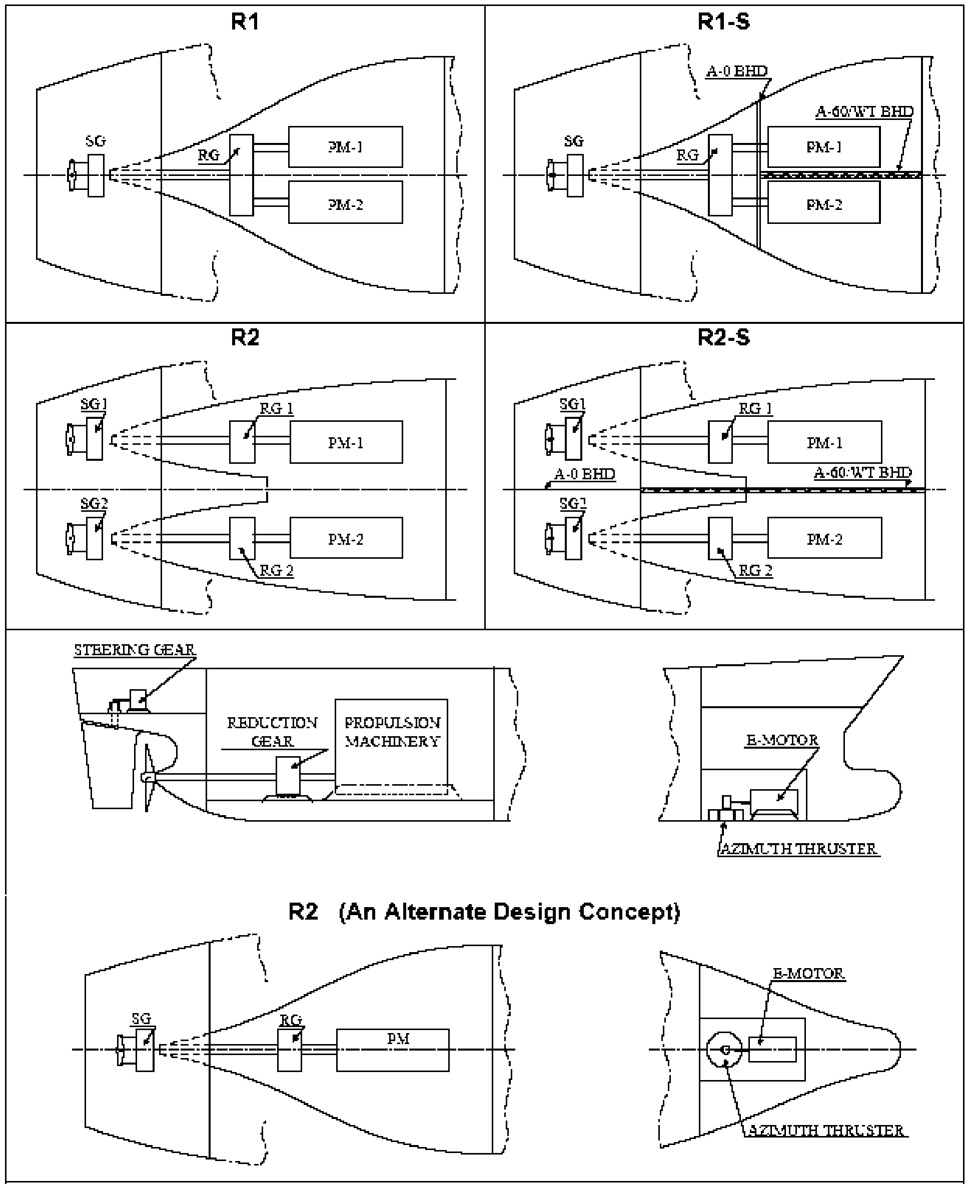

Figure 7-5: Arrangements of Engine Spaces for Redundant Systems
(Figure 1 of Ref. 3, Part 4, Chapter 3, Section 6)

7.7.2 DNV Redundant Propulsion Notation

Det Norske Veritas (DNV) has also developed rules for classing redundant propulsion machines and systems in ships [Ref. 16]. Two notations are available based on the bulkhead separation of the propulsion systems.

The basic requirement for either redundant propulsion notation (RP or RPS) is to restore at least 50% of the propulsion after a single failure in the propulsion system. The system must be restored before the vessel has lost steering speed.

In addition, the 50% restored power must enable the vessel to maintain a speed of not less than 6 knots while heading into Beaufort 8 weather conditions with corresponding wave conditions.

The RPS notation adds two failure criteria to the list of typical failures that may cause a propulsion system to shut down. These are fire and flood. By adding a watertight and A-60 fire rated bulkhead, the two propulsion systems are truly independent from all conceivable failure modes.

The steering system is to be of redundant design, consisting of two rudders and steering gear. It must be maintained by emergency power upon loss of main power.

For the RP notation, electric power distribution must be arranged for automatic separation upon either failure of power supply or short circuit. For the RPS notation, switchboard sections must be separated by an A-60 fire rated bulkhead but can be connected for cross feeding.

All auxiliary and control systems must be arranged so that 50% of the propulsion power can be maintained after any single failure, including fire and flood for the RPS notation. RP notation allows sharing of fixed piping units, while RPS notation requires completely separate systems.

7.7.3 California Code of Regulations Redundancy Description

In the California Code of Regulations [Ref. 9], tanker vessel escort regulations do not apply to tankers having a fully redundant steering and propulsion system and a federally compliant navigation system. Fully redundant steering and propulsion systems must include all of the following:

- Two independent propulsion systems each with a dedicated propeller, engine (or motor), electrical generation system, electrical system (including the switchboard), fuel system, lube oil system, and any other system required to provide the vessel with independent means of propulsion
- Two independent rudders, each with separate steering systems
- The propulsion and steering components, as described in Subsection (A) and (B) above, shall be arranged in separate spaces, such that a fire or flood in one space will not affect the equivalent system in the other space(s)
- A bow thruster with an assigned power source

8 OTHER TANKER ESCORT SYSTEMS

This section describes and compares the Washington State Pilotage Act and current Puget Sound practice to other tug escort systems in place at Prince William Sound, California, Newfoundland and also to European escort requirements and practice.

8.1 WASHINGTON STATE PILOTAGE ACT

The Washington State Pilotage Act under the Revised Code of Washington (RCW 88.16.170) prevents laden oil tankers and any vessel designed for carrying cargo of liquefied natural or propane gas greater than 125,000 deadweight tons from entering Puget Sound beyond a line extending from Discovery Island light south to New Dungeness light.

The Act requires minimum safety features that the above mentioned types of vessels over 40,000 gross tons must comply with in order to be unescorted. These safety features include minimum horsepower requirements, twin propellers, double bottoms and dual radar. But due to the high horsepower requirement – on the order of twice the horsepower typically installed – no vessel satisfies this rule.

If a vessel does not meet these safety requirements, it must be escorted by a tug or tugs with combined horsepower of no less than 5% of the deadweight of the escorted tanker. Due to the horsepower safety requirement, no current tanker of single or dual propulsion unit meets this requirement.

To summarize, any sizable oil, natural gas or propane tanker transiting Puget Sound cannot transport more than 125,000 deadweight tons, and must have an escort tug (or tugs) with horsepower equal to at least 5% of escorted tanker's deadweight.

8.2 NORTH AMERICAN WEST-COAST PORTS

8.2.1 Prince William Sound, Alaska

Part 168 of 33 CFR, "Escort Requirements for Certain Tankers" is applicable in these waters. This regulation requires at least two escort vessels be immediately available for single hull tankers over 5,000 gross tons. The escort vessels are to be available to influence the tankers' speed and course in the event of a steering or propulsion equipment failure. The regulation outlines the requirements for the escort vessels.

The Alaska Administrative Code (AAC) has created 18 AAC 75, Oil and Other Hazardous Substances Pollution Control, that requires every tanker carrying crude oil to submit an oil discharge prevention and contingency plan.

Alyeska Pipeline Service Company has created a port-specific Vessel Escort and Response Plan (VERP) for the tankers exporting crude from Port Valdez, Alaska. It is designed to provide operating procedures for the effective use of the escort vessels in the event of an equipment failure aboard the tanker. It also provides information regarding the capabilities of the Prince William Sound escort vessels. All tankers operating within Prince William Sound are required to follow the operating procedures detailed within the VERP.

The VERP manual describes speed limits for laden and ballast tankers in various areas or zones of Prince William Sound. It also requires the use of combinations of specific tugs based on tanker deadweight tonnage and weather conditions. When wind speed is above 40 knots, transit of any size tanker is prohibited.

To address these needs, tug operating companies in Prince William Sound have three Voith fin-first tractor tugs up to 105 tons bollard pull. In addition, three Z-drive tractor tugs up to 120 tons bollard pull provide untethered escort service as well as other harbor services.

8.2.2 San Francisco Bay

Within the California Code of Regulations, 14.4.4.1 "Tank Vessel Escort Regulations for the San Francisco Bay Region" requires that tank vessels carrying 5,000 or more long tons of oil as cargo shall be escorted by a suitable escort tug or tugs. No federal tanker escort regulations apply to California ports.

The concerned area includes San Francisco Bay, San Pablo Bay and Suisun Bay. These areas are broken up into six zones. Zones 1 and 2 are grouped together and require minimal escort tug breaking force due to channel width, depth, traffic and environmental forces. Zones 4 and 6 are grouped together and require escort tugs with more severe breaking force. These forces are provided as a function of the escorted tanker's displacement and the assisting current in a table. Zones 3 and 5 do not require escorting.

All tank vessel masters shall use an approved escort plan for transit through zones 1, 2, 4 or 6. No more than three tugs are permitted for the escort. All tank vessels must comply with a 10-knot speed limit through zones 1, 2, 3 and 5; and an 8-knot speed limit through zones 4 and 6.

Sufficient tug performance is achieved by referring to a table provided in the Regulations. The table matches tug braking pull to tanker size in deadweight tons, taking into account up to 4-knot currents commonly found in San Francisco waters.

As an alternate to using the braking force tables provided, an Alternate Compliance Model for Escort Tugs may be developed to demonstrate an alternate method for measuring the breaking and steering force of any tug. The measurement must be conducted by an approved marine architect or engineer and submitted to the administration for approval.

An Alternate Compliance Model for Tankers can be also submitted. In the same respect, these models must demonstrate increased braking and maneuverability aspects of tankers.

If a tanker has a double hull, a fully redundant steering and propulsion system, a bow thruster and a federally compliant navigation system, then it is exempt from the state escort requirements.

Barges fall under different requirements. The escort tug(s) must have a total astern static bollard pull in pounds equal to or greater than the barge's deadweight tonnage.

Tugboat owners and operators have over 30 tugboats in the San Francisco Bay area waters to meet these requirements. Two Voith fin-first tractor tugs with 64 and 85 tons bollard pull are the most agile and effective escort tugs in the area. Tractor tugs with Z-drives number about 18, with the largest having about 100 tons. There are at least 10 conventional twin-screw tugs with bollard pull of 35 tons or less.

8.2.3 Los Angeles/Long Beach

Within the California Code of Regulations, 14.1.4.4.2, "Tank Vessel Escort Program for the Los Angeles / Long Beach Harbor" requires that tank vessels carrying 5,000 or more long tons of oil as cargo shall be escorted by a suitable escort tug (or tugs). No federal tanker escort regulations apply to Californian ports.

The applicable nautical area includes any area inside the Federal Breakwater and within the pilot operating area for inbound vessels only.

Tanker and escort tugs must be matched using a force selection table provided in the regulations. It provides the required bollard pull as a function of escorted tanker displacement and tug type. It also provides second tug ratios allowing for matching of up to two tugs. A single tractor or conventional tug can be used, as well as any combination of the two types. Tractor tugs shall be tethered at all times and conventional tugs need only be tethered going outbound, but can be tethered inbound as well.

Tugs shall measure their static bollard pull by complying with the regulation's typical testing requirements and then providing the results to the Los Angeles / Long Beach Harbor Safety Committee.

As an alternate to static bollard pull test requirements, escort tug operators may propose an alternative method for measuring breaking and steering forces developed by the escort tug. The measurement must be conducted by an Administrator-approved naval architect or licensed marine engineer.

As an alternate to the tanker and tug matching criteria supplied in the regulations, a model for tankers can be also submitted. These models must demonstrate increased braking and maneuverability aspects of tankers and must be conducted by an Administrator approved naval architect or licensed marine engineer.

If a tanker has a double hull, a fully redundant steering and propulsion system, a bow thruster and a federally compliant navigation system, then it is exempt from the escort requirements stated above.

All tank vessels of 60,000 displacement tons and less must comply with an 8-knot speed limit. Vessels exceeding this displacement must comply with a 6-knot speed limit.

Barges fall under different requirements. Barges with less than or equal to 20,000 displacement tons shall have a tethered or untethered escort tug (or tugs) having a minimum bollard pull equal to 10 or 15 short tons, respectively.

If the barge is over the 20,000 deadweight tons limit, the total tonnage of the barges and towing tug must be less than or equal to the total astern bollard pull of a tethered escort tug (or tugs).

In either case, no more than two escort tugs are permitted to provide the breaking force specified.

To meet these requirements, six Voith fin-first tractor tugs are currently in service in the subject waters. Four of this type have a bollard pull of 40-50 tons and two have 30-40 tons. In addition, eight Z-drive tractor tugs having up to 76 tons bollard pull and 10 conventional twin-screw tugs having up to 50 tons bollard pull also serve the area.

8.3 NORTH AMERICAN EAST-COAST PORTS

8.3.1 Placentia Bay, Newfoundland

Only one port on the North American east coast conducts tanker escorting. This escorting is the voluntary practice of the owners of the Whiffen Head Transshipment Terminal in Newfoundland. This terminal is located at the North end of Placentia Bay.

The terminal receives crude oil shuttle tankers from offshore fields and exports crude oil on conventional tankers. Two Voith tractor tugs, each having 5,600 horsepower and about 55 tons bollard pull, perform escorting, docking and firefighting duties.

Laden tankers, either departing or arriving at the terminal, are required to be escorted by at least one tractor tug. Inbound tankers are escorted from the pilot station to the terminal or safe anchorage (about 28 nautical miles). Outbound loaded tankers are escorted from the terminal to the southern ridge, south tip of the Merasheen Banks (about 48 nautical miles).

The maximum inbound and outbound speed limit for tethered tankers is 6 and 8 knots, respectively. Tethering of the escort tugs is not mandatory but is assessed based on environmental and tanker conditions.

8.4 EUROPEAN ESCORT REQUIREMENTS AND PRACTICE

Throughout Norway, Sweden, Finland and the UK, no governmental regulations require escorting in specific ports. However, many ports in these areas perform tanker escorting initiated by port authorities, terminals, refineries and, in the case of Norway, the Coastal Directorate.

8.4.1 Norway

There are currently two ports performing escorting of laden tankers in Norway. These are Mongstad and Rafsnes, which contain oil terminals owned by Statoil and Norsk Hydro, respectively. Agreement to escort and the practice to be adopted has been developed by the port authority, terminal owners and the Coastal Directorate.

The Norwegian classification society Det Norske Veritas (DNV) has developed an escort notation for escort tugboats. All escort tugs operating in Norway are required to have the escort notation. This notation recognizes tons steering force per deadweight ton of escorted tankers and includes full scale testing to validate the notation.

In addition, it is specified in escort agreements that all tankers must meet the Oil Companies International Marine Forum (OCIMF) recommendations for fastening devises for escort tug tether attachment point.

Norwegian ports of Sture and Snoehvit have plans to start tanker escorting in the next few years, while Karstoe and Aukra may adopt tanker escorting in the future.

Two main towing companies serve all the ports of Norway. In addition, these tugs also serve other nearby countries. Their combined fleets comprise 8 Voith and 13 Z-Drive tractor tugs having up to 95 and 90 tons bollard pull, respectively.

8.4.2 Sweden

The two ports of Brofjorden and Gothenburg in Sweden practice tanker escorting. Brofjorden was the first port in Sweden to develop tanker escorting policy in 1998. In addition to the above, other ports are considering escorting tankers in the future.

Practice and escorting agreements are essentially the same as those of Norway.

Norwegian tugs commonly serve ports in Sweden. One major tug company operates solely in Sweden and its fleet is composed of 1 Voith tractor tug with 57 tons bollard pull, and 6 Z-drive tractor tugs with up to 61 tons bollard pull.

8.4.3 Finland

At least one port in Finland currently escorts tankers. Porvoo refinery is owned by Fortum Oil Company and located in Porvoo, Finland. They have purchased two new-build Z-drive DNV escort tugs rated at 70 tons bollard pull with an ice class 1A notation. All inbound and outbound laden tankers are escorted to and from the refinery by these tugs.

8.4.4 United Kingdom

Like the Scandinavian countries, the U.K. does not have specific governmental requirements for laden tanker escorting and individual ports have adopted this practice to mitigate oil spill risk. Sullom Voe, Milford Haven and Liverpool on the Mersey River all practice tanker escorting of varying degrees. Sullom Voe has the longest history of tanker escorting and an advanced oil spill response plan.

A tug escort simulator has been built near Liverpool and is currently operational. The simulator is being used to make safer the transit of vessels on the Mersey River and transit to Shell's Tranmere Oil Terminal.

In addition to simulations, the port authority of Milford Haven has conducted full scale tests of a 66-ton bollard pull Z-drive tug with accompanying tanker. This two day trial was designed to establish and record the ability of the tug to affect the speed and course of the loaded tanker. The information gathered from this test has been used to validate simulation models and ultimately improve the safety at the port of Milford Haven.

Sullom Voe uses two Voith tractor tugs with 45 to 56 tons bollard pull. Milford Haven uses four Z-drive tractor tugs with 45 to 66 tons bollard pull. Liverpool uses three Z-drive tractor tugs with 50 to 55 tons bollard pull.

8.5 COMPARISON

It is clear when comparing the Washington State escorting regulations and practice to those of Alaska, California and Europe, a better definition of requirements is necessary to properly protect Puget Sound from environmental damage.

The Washington State Pilotage Act defines the escort tug requirements as a function of displacement. This is also done in Norway and in California. In Norway, the DNV classification society has developed a curve relating tons steering force to escorted tanker deadweight tonnage. In San Francisco, California, effectiveness of tugs is measured in braking force and related to escorted tanker deadweight tonnage.

However, contrary to San Francisco and Norway, Washington State uses a horsepower rating to specify the escort tug performance as a function of deadweight tonnage of the escorted tanker. As demonstrated in the *Arco Juneau – Lindsey Foss* full scale tests conducted by The Glosten Associates in April 1997, the true measure of an escort tug is not solely dependent on horsepower, but on design and propulsion type. In some fin-first Voith tractor tug designs, the steering force and braking force can be nearly twice that of the static bollard pull at a high escort speed. Horsepower is therefore somewhat independent of the tugs' escorting effectiveness.

In San Francisco, navigable waters are broken up into zones that are based on environmental conditions and channel characteristics such as width, curvature and depth. As specified in the regulations, different speeds and escorting requirements are divided into these zones. There have been produced for towing service companies tanker escort manuals that divide Puget Sound into six zones based on location and channel width.

Washington State regulations do not restrict speed. Both California and Alaska restrict the speed of vessels in narrow passages such as Valdez Narrows in Alaska and Carquinez Strait in California. Guemes Channel and Anacortes to Rosario Strait in Puget Sound, for example, may warrant similar speed restrictions.

Table 8-1 summarizes the regulations and available equipment at the different ports.

Table 8-1: Summary of Regulations and Available Escort Equipment at Different Ports

Location	Escort Required	Escort Regulations	Available Escort Equipment
Puget Sound, WA	**Yes**. **Oil Pollution Act of 1990 (OPA 90)** (33 CFR 168) and **Washington State Pilotage Act** (RCW 88.16.190).	**OPA 90 (a):** Single hull tankers over 5,000 gross DWT require at least 2 escorts. Escort requirements: 1. Hold tanker in position against aligned 4-knot current and 45-knot wind; 2. Provide equivalent stopping distance as able tanker at 6 knots; 3. Hold tanker at steady course against 35° locked rudder at 6 knots; 4. Provide equivalent advance and transfer distance with free rudder as able tanker with hard-over rudder. **OPA 90 (b):** All tankers Regulations in part (a) are minimum. Master must take appropriate precautions, including speed reductions when necessary, in order to operate vessel in safe, prudent manner. **Washington State Pilotage Act:** All tankers above 40,000 gross DWT require escort. Exemptions possible, but no vessels exist due to large horsepower requirement. No tankers above 125,000 DWT permitted in Puget Sound. Escort requirements: Tug(s) total horsepower $\geq$ 5% of tanker gross DWT	**11 Voith® tractors:** 3 @ 70-80 mtons bollard pull 2 @ 50-60 mtons bollard pull 4 @ 49 mtons bollard pull 2 @ 35 mtons bollard pull **2 Z-Drive tractors**: 1 @ 75 mtons bollard pull 1 @ 41 mtons bollard pull **15 Twin screw:** 6 @ 60-70 mtons bollard pull 4 are standard; 2 are Nautican-type with high performance rudder 1 @ 54 mtons bollard pull – standard 4 @ 40-50 mtons bollard pull 2 are standard; 2 are Kort-type 4 @ 30-40 mtons bollard pull 3 are standard; 1 is Kort-type
Prince William Sound, AK	**Yes.** **Oil Pollution Act of 1990 (OPA 90)** (33 CFR 168) and **Alaska Oil and Other Hazardous Substances Pollution Control** (18 AAC 75)	**OPA 90:** (see description above) Port specific requirements for TAPS trade tankers are created by Alyeska Pipeline Service Company and named the Vessel Escort and Response Plan (VERP) **Alaska Oil and Other Hazardous Substance Pollution Control:** All tank vessels and oil barges operating the waters of the state must have an approved oil discharge prevention and contingency plan. Approval granted by Alaska Department of Environmental Conservation. Speed limit of 6 knots in Valdez Narrows.	**3 Voith® tractors:** 2 @ ~105 mtons bollard pull 1 @ 55 mtons bollard pull **3 Z-Drive tractors**: 3 @ ~120 mtons bollard pull
San Francisco Bay, CA	**Yes.** **Tank Vessel Escort Regulations – San Francisco Bay Region** (CCR 14.4.4.1)	**Tank Vessel Escort Regulations – San Francisco Bay Region:** Escort tug(s) required for tank vessels carrying 5,000 or more long tons of cargo oil. 1. Zone-dependent braking force is function of tanker displacement. Alternate compliance plan is allowed. 2. Zone-dependent speed limit of 8 or 10 knots. 3. Exemption requires double hull, redundant steering and propulsion, bow thruster, federal compliant navigation system.	**2 Voith® tractors:** 1 @ 85 mtons bollard pull 1 @ 64 mtons bollard pull **18 Z-Drive tractors**: 3 @ 90-100 mtons bollard pull 5 @ 80-90 mtons bollard pull 2 @ 50-60 mtons bollard pull 5 @ 40-50 mtons bollard pull 3 @ 30-40 mtons bollard pull **10 Twin screw:** 1 @ 33 mtons bollard pull – Kort-type 7 @ 20-30 mtons bollard pull 6 standard; 1 Kort-type 11 @ < 20 mtons bollard pull

Los Angeles and Long Beach, CA	**Yes.** **Tank Vessel Escort Regulations – Los Angeles / Long Beach Harbor** (CCR 14.4.4.2)	**Tank Vessel Escort Regulations – Los Angeles / Long Beach Harbor:** Escort tug(s) required for tank vessels carrying 5,000 or more long tons of cargo oil. 1. Tug-type-dependent braking force is function of tanker displacement. Alternate compliance plan is allowed. 2. Speed limit: 8 knots if < 60,000 displacement 6 knots if > 60,000 displacement 3. Exemption requires double hull, redundant steering and propulsion, bow thruster, federal compliant navigation system.	**6 Voith® tractors:** 4 @ 40-50 mtons bollard pull 2 @ 30-40 mtons bollard pull **8 Z-Drive tractors**: 1 @ 76 mtons bollard pull 2 @ 50-60 mtons bollard pull 4 @ 40-50 mtons bollard pull 1 @ 36 mtons bollard pull **10 Twin screw:** 1 @ 50 mtons bollard pull – standard 3 @ 30-40 mtons bollard pull 2 standard; 1 Kort-type 1 @ 22 mtons bollard pull – Kort-type 5 @ < 20 mtons bollard pull 3 standard; 2 Kort-type
Whiffenhead, Newfoundland	**No.** **Newfoundland Transshipment Limited Voluntarily Practices.**	**Newfoundland Transshipment Limited Voluntary Practices:** Escort tugs are used for inbound and outbound laden tankers.	**2 Voith® tractors:** 2 @ ~55 mtons bollard pull
Norway **Mongstad & Rafsnes** **More ports plan to start escorting and others under consideration**	**No.** **Port, Terminal Owners (Statoil & Norsk Hydro) and Costal Directorate Voluntary Practice**	**Individual Ports and Terminals Voluntary Practice:** Escort tugs are used for inbound and outbound laden tankers. Escort notation required by DNV Escort tugs are sized based on Tonnes Steering Pull and Tanker DWT, derived by DNV from IMO 10/10 zigzag turns at 10 kts. Tankers must meet OCIMF recommendations for fastening devises	**8 Voith® tractors:** 3 @ 90-95 mtons bollard pull and 155-160 mtons steering pull at 10 kts 2 @ 60-70 mtons bollard pull and 130-150 mtons steering pull at 10 kts 3 @ 45-50 mtons bollard pull and 90-100 mtons steering pull at 10 kts **13 Z-Drive tractors**: 1 @ 90 mtons bollard pull and 130 mtons steering pull at 10 kts 4 @ 57-62 mtons bollard pull 5 @ 42-50 mtons bollard pull 3 @ 35 mtons bollard pull Represents two towing companies' fleets also serving Sweden
Sweden **Brofjorden & Gothenburg** **Other ports under consideration**	**No.** **Port, Terminal Owners (Scanraff Refinery & Stena Oil) and Coastal Directorate Voluntary Practice**	**Individual Ports and Terminals Voluntary Practice:** Escort tugs are used for inbound and/or outbound laden tankers. Escort notation required by DNV Escort tugs are sized based on Tonnes Steering Pull and Tanker DWT, derived by DNV from IMO 10/10 zigzag turns at 10 kts. Tankers must meet OCIMF recommendations for fastening devises	**1 Voith® tractors:** 1 @ 57 mtons bollard pull **6 Z-Drive tractors**: 1 @ 61 mtons bollard pull 2 @ 53 mtons bollard pull 3 @ 38 mtons bollard pull Represents one towing company's fleet
Finland **Porvoo**	**No.** **Port and Refinery Owner (Fortum) Voluntary Practice**	**Individual Port and Refinery Voluntary Practice:** Escort tugs are used for inbound and outbound laden tankers. Ice class 1A and Escort notation provided by DNV	**2 Z-Drive tractors**: 2 @ 70 mtons bollard pull
United Kingdom **Sullom Voe Scotland, Milford Haven & Liverpool England**	**No.** **Port and Terminal Owners (BP, Chevron Texaco, Petroplus, ELF & Shell) Voluntary Practice**	**Individual Ports and Terminals Voluntary Practice:** Escort tugs are used for inbound and/or outbound laden tankers.	**Sullom Voe** – 2 Voith® tractors @ 45-56 mtons bollard pull **Milford Haven** – 2 Z-Drive tractors @ 66 mtons bollard pull 2 Z-Drive tractors @ 45 mtons bollard pull **Liverpool** – 5 Z-Drive tractors @ 50-55 mtons bollard pull

9 RISK MANAGEMENT IN THE WASHINGTON TUG ESCORT SYSTEM

This section describes and discusses the range of technological, human and external factors influencing risk management in the Washington State tug escort system. The work was performed by Martha Grabowski, Ph.D., under sub-contract to The Glosten Associates.

The first sub-section provides an overview of risk management and discusses the challenges of risk management in complex systems. Section 9.2 discusses technological, human and external factors that influence risk management in the Washington State tug escort system, as well as some implications of these factors. Section 9.3 addresses available alternatives that could compensate for the benefit of the auxiliary bridge and scout capabilities provided by the current tug escort system. Section 9.4 discusses the limitations of the concepts in this risk management analysis.

Summary

Effective risk management requires integration of defenses, of safety information systems, of operators and of risk models. The integration of defenses, risk models, operators and organizational culture should also suggest consistent risk mitigation measures such as training; safety management systems and crew certification and re-certification programs. Assessing some of the human, technological and external factors that influence risk management in the Washington State tug escort system is not without challenges. However, the concepts given in this report provide structure, direction and analytical support that are critical when managing risk in complex systems.

9.1 RISK MANAGEMENT IN COMPLEX SYSTEMS

Risk may be defined as the measure of the probability and severity of an unwanted event. Risk events occur for a variety of reasons. Sometimes they are the result of *basic or root causes*, such as inadequate operator knowledge, skills or abilities, or the lack of a safety management system in an organization. They can also result from *immediate causes*, such as a failure to apply basic knowledge, skills or abilities, or an operator impaired by drugs or alcohol. *Incidents* are unwanted events that may or may not result in accidents; *accidents* are unwanted events that have either *immediate* or *delayed consequences.* Immediate consequences could include injuries, loss of life, property damage and persons in peril. Delayed consequences could include further loss of life, environmental damage and financial costs. Risk events often occur because the error chain *cascades:* a basic cause can occur *and* an immediate cause *and* an incident will trigger an accident [Ref. 87]. Without risk reduction measures to interrupt the error chain, basic causes can cascade into immediate causes, which can cascade into an incident, which can trigger an accident. The key to risk mitigation, therefore, is to introduce risk reduction interventions at appropriate points in the error chain so as to prevent the cascade.

Risk in complex systems can have its roots in a number of factors. One cause may be that activities performed in the system are inherently risky (e.g., mining, surgery, airline transportation); another may be that technology used in the system has risk associated with it (e.g., heavy equipment, lasers and aircraft). Individuals and organizations executing tasks, using technology or coordinating activities also create risk. Organizational structures in a system may unintentionally encourage risky practices (e.g., with the lack of formal safety reporting systems in organizations, or organizational standards that are impossible to meet without some amount of risk taking). Organizational cultures also may support risk taking or fail to sufficiently encourage risk aversion [Refs. 36-38, 59, 81, 90 & 115].

Risk management in complex systems presents interesting challenges. First, when elements in the system are distributed, risk in the system can migrate, making risk identification and mitigation difficult. Risk migrates when the introduction of a risk mitigation measure to address one problem in the system introduces other, unintended consequences in another part of the system. An example of risk migration can be seen when weather-related delays cause vessels to stay in port until the weather clears. During the restricted visibility, the risk of collision on arrivals and departures decreases, but when the weather clears, the risk of collisions between vessels beginning to move increases [Ref. 116].

Risk management in complex systems is also difficult because incidents and accidents in the system can have *long incubation periods,* which can make identification of leading error chains difficult. When systems have long incubation periods, precipitating factors may lie dormant for long periods of time, until catalyzed by the right combination of triggering events (i.e., chemical reactions that provide the right catalyst, interacting personalities on a vessel that cause dysfunctional organizational and behavioral reactions, or technologies being utilized in previously unforeseen, pathological ways). Long incubation periods provide particular challenges for risk managers observing short-term changes in a dynamic system [Ref. 87].

Finally, risk management in complex systems is difficult because such systems often have organizational structures with limited physical oversight, which makes the process of identifying and addressing human and organizational error complicated. In a distributed system with limited physical oversight, the normal antidotes to human and organizational error—checks and balances, redundancy and training—may be defeated by the size and scope of the system, or by subcultures that can develop in the system. In marine transportation, for instance, there are numerous opportunities for human and organizational error because of the tempo of operations, volume of information, criticality of decisions and actions, and complexity of interactions that exist in the system [Refs. 71, 74 & 76]. As marine operations move in an increasingly distributed, electronic direction, it may be increasingly difficult to assess and identify the role of human and organizational error, and its impact on levels of risk in the system [Refs. 38 & 40].

These observations have implications for risk management in complex systems. To counter the problem of risk migration, dynamic risk assessment models can be used to capture the dynamics of the complex system, as well as patterns of risk migration. Long incubation periods in a system suggest the importance of historical analyses of system performance in order to establish performance benchmarks in the system, and to identify patterns of triggering events, which may require long periods of time to develop and detect. Finally, assessments of the role of human and organizational error, and its impact on levels of risk in the system, are critical in distributed, large-scale systems with limited physical oversight.

9.2 FACTORS INFLUENCING RISK MANAGEMENT IN THE WASHINGTON STATE TUG ESCORT SYSTEM

In this section, we consider risk management and its challenges in complex systems as they apply to the Washington State tug escort system. We begin by considering the elements of the risk error chain as they apply to the tug escort system, and then the concepts of risk migration, long incubation periods, the challenges of limited physical oversight and the need for checks and balances. This section provides an overview of concepts that explore the role of technological, human and external factors in risk management in the Washington State tug escort system.

Risk events in the Washington State tug escort system can occur for a variety of reasons, as outlined in 9-1, above. *Incidents* are undesirable events related to control or system failures that can be detected or corrected in time to prevent accidents; incidents can also be prevented from developing into accidents by the presence of redundant or back up systems. Examples of incidents in the Washington State tug escort system include vessel or tug propulsion failures, steering failures, navigational equipment failures and other equipment failures. *Accidents* are occurrences that cause damage to vessels, tugs, facilities or personnel. These include collisions, allisions, groundings, fires, explosions and founderings. The potential *impacts* can include environmental damage, deaths, injuries, loss of equipment and economic losses that occur as an immediate or delayed consequence of an accident.

There is inherent risk in managing the Washington State tug escort system. Tasks in the system (navigation, vessel loading, propulsion plant engineering, arrivals and departures) are distributed across a large geographical area, are time-critical and contain elements of embedded risk (e.g., vessel navigation in congested waters, in reduced visibility, on time-critical schedules). The technology used in the system (vessels, equipment, software, control systems, mooring lines, etc.) also has elements of embedded risk. Because people and organizations are critical elements in the system, human and organizational error is inherently present, and organizational structures that result in limited physical oversight and contact can make risk mitigation difficult. Finally, as in many large-scale systems, confusing or contradictory messages may emanate from one of its sectors (e.g., safety bulletins in one company that promote practices that are sanctioned in other organizations).

The risk management challenges introduced in Section 9.1 are clearly present in the Washington State tug escort system. Since the tug escort system is a distributed system, with members physically and geographically separated by time and distance, risk in the system can *migrate*, particularly when risk mitigation measures are introduced. For example, one risk problem may be solved with the introduction of a risk mitigation measure (i.e., a requirement for tug escorts at the tanker's bow and stern, or requirements for redundant tug lines), at the same time that new risk problems can emerge as a result of the introduction of that measure (i.e., the time it takes for an additional tug or tug line can decrease the safety margin, increase vessel and tug vulnerability, or introduce another set of potential failures).

In the Washington State tug escort system, precipitating factors may have long incubation periods, and pathological risk factors may lie dormant for long periods of time until catalyzed by the right combination of triggering events. In the case of the *Exxon Valdez*, those precipitating factors included ice in a channel, a tired crew, a nighttime passage, a captain with impaired decision making abilities, and a host of crew failures, such as mistakes in helm orders, locked-on autopilots and missed warnings provided by navigational aids. Clearly, dormant risk factors such as these could be catalyzed by the right combination of triggering events. Identifying dormant risk factors with long incubation periods can be difficult, however, when risk managers focus on short-term observations and results.

The Washington State tug escort system is, by definition, a distributed system, with limited physical oversight of its members. Traditional antidotes to limited physical oversight—redundancy in the system, training, checks and balances—can be impeded by the size and scope of the system, or by subcultures that develop within it. Thus, it is important to identify and assess the role of human and organizational error, as well as organizational structure and behavior, in the system, as both are cited as important contributors to accidents in marine transportation. In the following section, we discuss technological, human and external factors and their influences on risk management in the Washington State tug escort system.

9.2.1 Technological Factors

Risk events can even occur in complex systems with in-depth defenses – protective measures possessing a great deal of diversity and redundancy [Ref. 85]. Examples of such well defended technological systems include the Washington State tug escort system, which has a mix of *hard* and *soft* defenses. Hard defenses include engineered safety features, such as automatic controls, redundancy, warning systems and shutdowns, together with various physical barriers and containments, while soft defenses comprise a combination of people, rules and procedures, training, drills, administrative controls and, most particularly, trained vessel and tug operators. The intended result of these layers of defense is to protect the system against single failures, either human or technical. For an accident to occur in such a system, it usually requires the unlikely combination of several different factors to penetrate the different protective layers, allowing hazards to come into damaging contact with equipment, personnel and the environment [Ref. 85].

Hard and soft defenses have their gaps, however. Gaps can be created by active failures, such as the errors and violations of human operators, and by latent conditions arising from the failure of designers, builders, managers and maintainers to anticipate all likely scenarios [Ref. 87]. Gaps due to active failures are likely to be relatively short-lived, while those arising from latent conditions may lie dormant for many years until revealed by regulators, internal audits or by incidents and accidents. Thus, hard and soft technological defenses are a mixed blessing, as Reason points out [Ref. 85]:

> *While they greatly reduce the likelihood of a bad accident, they also render the system as a whole more opaque to the people who have to manage and operate it (Rasmussen, 1993)* [Ref. 84]. *The human controllers of such systems have become remote from the processes they manipulate and in many cases, from the hazards that potentially endanger their operations. Both this distancing effect and the rarity of bad events make it very easy not to be afraid, as was evident at the Chernobyl nuclear power station. Contrast this with a traditional 'close encounter' industry such as mining or construction. The working conditions may be brutal, but the dangers are very evident. Even where a poor safety culture has led to the provision of inadequate tools, equipment and protective measures, most workers will be wary of the all too apparent local hazards* (p. 296).

The complexity of the Washington State tug escort system may make the system opaque to some front-line operators, and it may also make it almost impossible for any one individual in the system to understand the system in its entirety [Ref. 81]. This can lead to the insidious accumulation of latent conditions that weaken the defenses [Ref. 85]. This is clearly a challenge for a well-defended system like the Washington State tug escort system.

9.2.2 External Factors

The Puget Sound marine transportation system presents a number of external challenges to effective risk management. Oil transportation is an important component of cargoes carried in the area, and oil transportation occurs year round in the Sound. Inclement weather and close navigational passages are key factors in the marine transportation system. Wind and wave conditions can be heavy, especially during the winter months. There are constant currents in the cold waters where oil is transported, with numerous islands. The shoreline includes many islands and beaches.

Much of the tanker traffic runs to the North Sound and San Juan Islands, and there is concentrated traffic in the approaches to Rosario and Haro Straits. Puget Sound pilots provide transit services for tankers transiting the Sound. Crossing and passing traffic in the Sound includes passenger/car ferries, fast ferries, container ships, log ships, small tugs and barges that often hug the shoreline, and float planes in Elliott Bay. However, once it is inside the approach, most of the tanker traffic does not transit Elliott Bay. A traffic separation scheme exists within Rosario Strait, which is used by the tankers as they transit to the North Sound refineries. Ferries also use the inland passages providing services to the individual islands and the mainland. Citizen involvement and interest in tanker traffic, transits and performance are high and the citizenry and politicians are highly involved in the regulatory processes.

In North Puget Sound and the San Juan Islands, where much tanker traffic transits, the marine and estuarine waters are biologically rich and ecologically sensitive. The shorelines, marine habitats and commercial seafood resources are widely diverse.

The region contains numerous small to medium seabird nesting colonies, several marine mammal breeding sites, spawning and feeding habitats for various fish species and invertebrates, and a resting area for migrating birds in the National Flyaway area. Many common species of whales and dolphins are found within the North Sound, as are many species of seals, sea lions and river otters [Ref. 70].

The San Juan shoreline borders the exposed areas of Rosario and Haro Straits, which are mostly composed of headlands. Most of the beaches in this area are open to the inside of the islands, which are generally sheltered rocky flats. The environment is neither conservancy, natural or rural [Ref. 70, p. 160]. The outer coast of the state, where tankers make their approach, encompasses approximately 75 miles of shoreline between Cape Flattery and Grays Harbor. The outer coast is ecologically rich and diverse, with some of the most scenic coastline in the world. Along the north coast is the Olympic Coast National Sanctuary, which is also designated a National Wildlife Refuge, a national park, a Biosphere Reserve and a World Heritage site.

Unlike most of Puget Sound, the outer coast is directly exposed to the constant waves and storms of the Pacific Ocean. The region is rich in marine life and is visited by many species of whales, dolphins and porpoises, seabirds, eagles, seals, sea otters and sea lions. Most of the outer coast is composed of mixed sand and gravel beaches that are interrupted by rocky headlands and islands that lie offshore. Several rivers that are spawning areas for salmon empty into the Pacific. Marsh and tidal flats exist at the mouths of the rivers [Ref. 70]. All of these external factors provide a challenging setting for risk management, as the area in which tanker transits and escorts occur is environmentally sensitive, navigationally restricted, and has natural and meteorological hazards.

9.2.3 Human and Organizational Factors

In complex systems it is challenging but important to assess the impact of human and organizational error on levels of risk in the system, especially as such error is often a primary contributor to accidents [Ref. 8]. Reason's cognitive framework of human error [Ref. 86] classifies unsafe acts into two types of activities: *errors*, which are unintended actions, and *violations*, which are intended actions. Errors can be of three types: *decision errors* (encompassing rule-based and knowledge-based errors), *skill-based errors* and *perceptual errors*. Violations can be either of two types: *routine*, which are commonplace abrogations of policies, rules and/or procedures that are condoned by management, or *exceptional violations*, which are not condoned by management.

In addition to Reason's cognitive error framework, it is important to consider a system's safety culture when considering that system's propensity toward risk and its risk management challenges. In well-defended systems, the defenses in the system can be widely distributed throughout the organization, reflecting both diversity and redundancy in defenses. As a result, the defenses in the system should be collectively vulnerable only to something that is equally widespread. Reason [Ref. 85] suggests that the most powerful influence required to bolster defenses in a complex system is the organization's safety culture: shared values (what is important) and beliefs (how things work) that interact with an organization's structures and control systems to produce behavioral norms ('how we do things around here') [Ref. 100].

An ideal safety culture is the 'engine' that drives the system towards its goal of sustaining the maximum resistance towards its operational hazards, in spite of an organization's commercial concerns [Ref. 85]. The power of this engine relies heavily on a continuing respect for the many entities that can penetrate, disable or bypass the system's safeguards. In short, it means not forgetting to be afraid. This is no easy task in industries with few accidents, such as the tug escort system. Reason suggests that in the absence of frequent bad events, the best way to induce and then sustain a state of intelligent and respectful wariness is to gather the right kinds of data [Refs. 85 & 115]. This means creating a safety information system that collects, analyzes and disseminates information from incidents and near misses, as well as from protective checks on the system's vital signs. All of these activities can be said to make up an informed culture—one in which those who manage and operate the system have current knowledge about the human, technical, organizational and environmental factors that determine the safety of the system as a whole. In most important respects, an informed culture is a safety culture [Ref. 85].

Human and organizational adaptations to challenges in well-defended systems may also cause gaps in that system. Take the case of the British Royal Navy in the mid-nineteenth century, which polished the watertight doors aboard warships until they were no longer watertight [Ref. 66]. The peacetime 'display culture' of Victorian warships not only undermined the Royal Navy's fighting ability, but it also created gleaming death traps—as in the case of the *HMS Camperdown* [Ref. 85]. Dangerous adaptations combined with innocuous operator choices in a system with few risk events can create situations that are ripe for error. The nuclear accident at Chernobyl is another example of dangerous adaptations combining with operator errors to produce catastrophic results [Ref. 67].

Far from being entirely random, however, accidents have a way of falling into recurrent patterns, shaped in large part by local operational circumstances. Reason [Ref. 85] recounts that in many of these recurrent accident scenarios, there are at least three common elements:

- *Universals.* These are ever-present hazards associated with the particular domain of activity. In the Washington State tug escort system, these would include rocks, shallows, currents and tides, the presence of other vessels, weather and visibility. It is unplanned contact with these universals that do the actual damage.

- *Local traps.* These are characteristics of the task or environment that, in combination with human error and violation tendencies, lure people into repeated patterns of unsafe acts or less-than-adequate performance. Such snares are likely to be enduring features of a particular work situation. The crucial feature of these snares is that they have the power to lure people into a series of unsafe acts, irrespective of who they are. Clearly, it is possible to resist these traps, but they nonetheless have a particular and persistent ability to lead people into danger.

- *Drivers.* The mere existence of local traps is insufficient to explain why people are repeatedly—but not invariably—ensnared by them. They are the necessary but insufficient causes of recurrent accidents. The sufficiency is supplied by something that drives people towards and then along these treacherous pathways. These drivers could include organizational pressures to cut costs, to increase margins, to arrive on time, or to avoid penalties. The argument to be offered here is that, in hazardous work, this motive force is derived from an organization's safety culture [Ref. 85, p. 301].

Reason suggests that some of the most powerful pushes toward local traps come from an unsatisfactory resolution of the inevitable conflict that exists between the goals of safety and productivity in safety-critical systems. In the pursuit of these goals in the Washington State tug escort system, the cultural accommodations must achieve a delicate balance.

9.3 ALTERNATIVES COMPENSATING FOR BENEFIT OF SCOUT OR AUXILIARY BRIDGE CAPABILITIES OF ESCORT TUGS

A central question in the Washington State Tug Escort project is whether there are potential modifications to the Washington State tanker escort requirements that recognize the safety enhancements of the new double-hull redundant-system tankers, and that maintain system safety for the area currently covered by Washington's tug escort requirements at a level equal to or greater than that associated with single-hull, non-redundant tankers escorted in accordance with RCW 88.16.190 and current escort practice as it has evolved to comply with both Washington State and federal law.

This section addresses whether there are alternatives available for the Washington State tug escort system that compensate for the benefit of the auxiliary bridge and scout capabilities provided by the current tug escort system. The section begins with a description of the functions provided by the current tug escorts—an analysis of functions tug escorts provide as scout and auxiliary bridges. The section then provides an overview of available alternatives to the functions provided by the tug escort scout and auxiliary bridge functions. Finally, the scout and auxiliary bridge tug escort functions are mapped to available candidate alternatives, and recommendations for alternatives are discussed. The section concludes with cautions about the limits of alternatives for the tug escort functions described.

9.3.1 Tug Escorts: Scout and Auxiliary Bridge Functions

Among the roles provided by tug escorts in the State of Washington tug escort system are those of scout and auxiliary bridge. As a scout, tug escorts provide redundant lookout and situation awareness functions to those provided on the tanker bridge, as well as physically distributed (from the tanker's bridge) perspectives on situation awareness, hazard avoidance and vessel positioning. In addition, tug escorts also serve as auxiliary bridges to the tanker bridge, providing provide redundant vessel positioning, situation awareness, hazards identification, and emergency response capabilities, as well as redundant bridge equipment to the tanker bridge. These are important roles and functions provided by the current tug escort system.

These roles are captured functionally in performance requirements for tug escorts. Tug escorts support the following requirements:

- Requirements for redundant *navigation,* supporting the tasks of vessel trackkeeping, maneuvering and collision avoidance, and the practice of good seamanship.

- Requirements for redundant *command and control decision making*, to support situation awareness, situation monitoring, threat identification, threat avoidance, system control and scenario display.

- Requirements for redundant *real-time and emergency response*, supporting the development and delivery of accurate required reasoning within specified response intervals.

In addition, tug escorts acting as scouts and auxiliary bridges also satisfy additional functional requirements for appropriate *organizational structure* in safety-critical systems, supporting the need for flexible organization structures, including checks and balances, heedful and varied organizational communications, decision making that migrates to the operational level, and the development of trust between the tanker bridges and the tug escort bridges. These functional requirements for tug escorts acting as scouts and auxiliary bridges are summarized in Table 9-1.

Table 9-1: Functional Analysis of Tug Escorts acting as Scouts and Auxiliary Bridges

Requirements	Tanker Bridge Teams	Tug Escorts	Alternatives to Tug Escorts
Navigation	M	R	R
Command and control decision making	M	R	R
Real-time and emergency response	M	R*	R*
Organizational structure	M	R	R

Key: M = mandatory support R = redundancy requirement R* = partial redundancy

Redundant Navigation Requirements

Ship navigation is largely a visually dependent activity that employs expert knowledge. The visually acquired information, such as information about navigational aids or landmarks, is processed, interpreted and acted upon, using three types of knowledge – local knowledge, transit-specific knowledge and knowledge of shiphandling [Refs. 39 & 74]. Tug escorts acting as scouts and auxiliary bridges provide redundant ship navigation functions to the tanker bridge. Thus, any alternatives to escort tugs must address requirements for redundant tanker navigation functionality.

Redundant Command and Control Decision Making Requirements

Command and control decision making requirements are derived from decision theory, which describe decision making as a process of evaluating and choosing from a set of alternative courses of action, often in a high-risk, stressful, time-constrained environment [Refs. 54, 61 & 74]. Tug escorts acting as scouts and auxiliary bridges provide redundant command and control decision making to the tanker bridge. Thus, alternatives to tug escorts must consider requirements for assessments of the current situation, monitoring the current situation, control of the situation to mitigate threats, and display of the current scenario and recommendations developed for the operator responsible for the decision making [Refs. 39 & 62].

Redundant Real-Time and Emergency Response Requirements

Real-time response requirements dictate that navigation and command and control decision making be integrated in a coherent fashion so as to produce accurate and reliable reasoning in real time. Real-time response requirements also include the necessity of integrating and responding appropriately to information from the tanker bridge watch teams, on-board navigation and information systems, and vessel traffic systems [Refs. 5, 74 & 76]. Supporting the above functionality as well as ensuring adequate response time implies access to reliable and timely data, such as ship speeds, headings, locations, locations of other vessels and radar targets, headings and speeds of those radar targets, ambient conditions, and current and flow conditions. This necessitates a real-time interface between internal shipboard, external and Vessel Traffic Systems (VTSs). *Emergency response requirements* dictate that activities in response to emergencies and threats are accomplished so as to aid the tanker crew and provide assistance as needed. Tug escorts acting in scout and auxiliary bridge roles are challenged to address requirements for redundant real-time response, as seen in Table 9-1, although they provide redundant support for emergency response requirements. As a result, alternatives to tug escorts acting as scouts or auxiliary bridges might only partially address requirements for redundant real-time response, or they might address those requirements more fully than the current tug escort system.

Organizational Structure Requirements

Tug escorts acting as scouts or auxiliary bridges also provide additional support to tanker bridges, in addition to the redundancy support just described. The organizational structure requirements, derived from the high reliability systems literature [Refs. 36-38, 89, 90 & 92], include requirements for flexible organizational structures, including checks and balances; varied and heedful communication structures; decision migration to the appropriate operational level; and the development of organizational cultures that share information, trust and commitment to error-free operations.

High reliability system researchers have produced a number of findings about organizational processes that provide insights into effective performance in safety-critical settings. One set of findings showed that organizations that must be successful all of the time, such as domestic tanker operations, continually reinvent themselves [Refs. 59, 95 & 114]. Weick [Ref. 114] described how such organizations flexibly structure and restructure themselves depending on environmental changes. Escort tugs in scout or auxiliary bridge roles provide an opportunity for ship's bridge crews to reconfigure tasks and responsibilities dynamically as situations evolve – for instance, to offload tasks between the tanker and the tug, or to load tasks differently between the two crews. Thus, tug escorts in scout or auxiliary bridge roles support organizational structure requirements for dynamic and responsive reconfiguration.

In high reliability systems, decision-making migrates to the lowest level consistent with the implementation in the interests of reliable operations [Ref. 91], and the maintenance of safe operations is an interactive, dynamic and communicative act, particularly vulnerable to disruption [Ref. 92]. Thus, distributed decision-making and open communications are important elements of high reliability systems. Escort tugs in scout and auxiliary bridge roles facilitate decision making at appropriate organizational levels, supporting the notion that decisions should be taken at the lowest, most appropriate operational level.

A final key finding was that high reliability systems build the kinds of cultures that are sharing, trusting, intolerant of error and clear about goals, and in which training is continuous [Ref. 56]. Escort tugs in scout and auxiliary bridge roles, however, may contribute to the development or perpetuation of differing organizational cultures in tanker operations – one aboard the tanker, another aboard the tug. However, the need for training tug crews in scout and auxiliary bridge roles is quite clear.

High reliability system research, therefore, suggests organizational structure requirements that are mostly fulfilled by tug escorts acting as scouts and auxiliary bridges. As a result, alternatives to tug escorts acting as scouts or auxiliary bridges should consider these requirements for organizational structure, as outlined in Table 9-1.

9.3.2 Candidate Alternatives

Given an understanding of the functional requirements that tug escorts in the Washington State tug escort system satisfy, it is now possible to consider a variety of alternatives that might also meet the functional requirements currently met by tug escorts in scout and auxiliary bridge roles. We first consider a range of available alternatives, and then the functional requirements of tug escorts acting as scouts and auxiliary bridges to those alternatives.

Navigation Alternatives

Recent advances in navigation technology have focused on making better information available to ship's masters and pilots, relieving them of more routine activities (for example, logistics, scheduling, record keeping; etc.), and thus freeing them to concentrate on the vessel's conduct through the waterway. These technological advances have been grouped into the following categories:

- Position fixing technology
- Steering and trackkeeping technology
- Passage/route planning technology
- Collision avoidance and surveillance technology
- Communications technology [Ref. 74]

Electronic chart technology offers a number of advantages over paper charts. Widespread availability of Global Positioning System (GPS) and Differential Global Positioning System (DGPS) receivers has greatly enhanced vessel position fixing accuracy while freeing the bridge personnel of the requirement to manually fix the vessel's position, although the need for secondary checking of electronic positioning by bridge personnel still remains an important requirement (National Transportation Safety Board, 1997). Improvements in communications have also made bridge-to-bridge communication easier. Automatic Radar Plotting Aids (ARPAs) greatly assist in the task of collision avoidance, and aids like steering systems integrated with the chart systems, rate of turn indicators, and autopilots, etc., have attained maturity in assisting steering and trackkeeping [Ref. 74].

Currently, the trend in navigation technology is towards the development of Integrated Bridge Systems (IBS), which project the ship's wheelhouse as the center of operational decision making aboard a ship, by integrating information from diverse on-board equipment and sensors and presenting them to the bridge watch team [Ref. 58]. Knowledge based systems that incorporate expert piloting and voyage planning knowledge are being embedded within an IBS, to provide decision support for navigational operations [Ref. 39].

Systems developed for ship's navigation decision support have evolved from standalone intelligent training systems to support specific functions, to embedded intelligent systems within a single ship's integrated bridge system, to distributed systems available to all vessels and vessel traffic service centers along a waterway. Further, efforts are being made to provide increasing intelligent support to the various subsystems of the marine transportation system. The increasing availability of advanced communication technologies such as local area networks, wide area networks, Automated Identification Systems (AIS), satellite navigation systems and the Global Positioning Systems (GPSs), have also made the concept of distributed systems with embedded intelligence feasible [Ref. 76].

Command and Control Decision Making Alternatives

A number of automated decision aids for shipboard command and control have been developed over the past decade. Coenen, Smeaton, and Bole [Ref. 10] describe an early design for a prototype standalone real-time knowledge-based ship's collision avoidance decision aid for open-water, multi-ship encounters. Hayashi, Kuwajima, Sotooka, Yamakazi, and Murase [Ref. 46] then describe a stranding avoidance system that combines an electronic chart system with overlaid radar images to aid in position fixing and situation assessment. The early advanced ship's bridge concepts described by Grove [Ref. 42] and Iijima and Hayashi [Ref. 50] each included decision aids for command and control.

A highly publicized application of expert system technology to ocean shipping has been the Japanese intelligent ship program [Ref. 50], which was carried out by the Japanese Shipbuilding Research Association with grants from the Japan Shipbuilding Industry Foundation, with assistance from seven major shipyards and six shipping lines in Japan. In this project, maneuvering and other command and control operations are performed automatically by an integrated system employing expert systems, digital communications via satellite to enable information exchange between ships and shore stations, and high performance sensors. The intelligent ship's subsystems (e.g., optimum navigation and course planning, oceanographic and meteorological systems, automatic docking and undocking systems, and automatic anchoring/mooring systems) are linked by a local area network and communicate with a *Captain Expert*: an expert system that incorporates the knowledge and experience of senior ship's masters. These subsystems are intended for use within a harbor, and allow the vessel to navigate and be docked at the pier in a totally automated manner without a vessel crew on board.

Other manufacturers have developed integrated command and control equipment and systems with similar functionality over the past decade. These systems typically integrate vessel positioning, maneuvering, control, communications, monitoring and situation display, often incorporating embedded intelligent decision aids to assist the ship's officer [Ref. 117].

Real-Time and Emergency Response Alternatives

Vessel traffic service services are interactive shore-based communications systems, usually augmented with surveillance equipment (principally radar) for acquisition of position and traffic flow data that provide information and navigation support services to improve navigation safety and traffic efficiency [Ref. 57]. A VTS also provides vessel crews with real-time and emergency response information that is critical in threat avoidance and emergency situations.

In practice, the VTS functions vary widely. VTSs have been predominantly used as a means to improve safety, efficiency and economic benefits in ports and waterways, especially those engaged in fierce competition; environmental objectives have also played a part. In keeping with the general trends in the marine transportation system, increasingly sophisticated equipment is being developed for VTSs. These include VHF-FM radio networks, radar, closed circuit and low light-level TV, infrared imaging devices, radar beacons, portable and fixed transponders, electronic charts and computer displays, position rebroadcasting systems and automatic recording systems. The deployment of increasingly intelligent decision support aboard the bridges of ships that pass through the VTS' spheres of influence have created pressure to incorporate similar decision support capabilities on VTS systems.

The Automated Identification Systems (AIS) is a communications protocol, developed under the aegis of the International Maritime Organization (IMO), that is in the process of worldwide implementation. With AIS and vessels using Global Positioning System (GPS) technology, any vessel equipped with an AIS transponder can transmit its location to a centralized station (often VTS centers) and to other similarly equipped ships on the waterway. The location of the vessel can be plotted on a computer display that shows where the vessel is on an electronic chart, together with its speed and course. Local VTSs may also add other pertinent information such as local wind speed and directions, water depths, ice conditions, availability of the next lockage and safety-related messages as dictated by circumstances. Such systems provide important technology assists to crews in need of real-time and emergency response information.

Many benefits of AIS have been projected. For vessels, AIS is projected to reduce transit times with accompanying lower fuel consumption. Since arrival times will be available in real time, better scheduling and real-time response is possible. AIS is also projected to enhance safety by transmitting precise environmental information in case of emergency.

AIS is also projected to enhance traffic management by continuously monitoring vessel location and speed in all weather conditions, permitting timely pilot dispatching, timely ship inspections, better speed control, better scheduling of lockages and vessel tie-ups, and faster response times to accidents and/or incidents, particularly when hazardous cargoes are involved. However, there is much discussion in the maritime community about the costs and benefits of AIS [Ref. 11] and the effectiveness of AIS displays [Ref. 76], particularly in the wake of collisions that might have been avoided with its use [Ref. 14].

Organizational Structure Alternatives

Alternatives to support tug escort requirements for organizational structure, communications, decision making and culture can take a number of forms. For instance, organizational structures can be dynamically recast in response to evolving situations through the use of embedded intelligent decision aids, as discussed in earlier sections.

Such technology also supports distributed decision making and, assuming that the user interfaces have been thoughtfully designed, can support effective, open and shared communication about evolving situations. However, unless sufficient attention has been given to the design and deployment of the technology interfaces, counter-intuitive and/or -productive results may develop [Refs. 39, 76 & 94]. Developing technology that facilitates the development of effective organizational cultures, particularly the development of trust, is much more of a challenge, with few empirical results available to describe the evolution of such technology [Ref. 39].

In the future, technology that supports the development of effective organizational structures, communication, decision making and cultures may not be as difficult to design, deploy and evaluate as it is today. Auxiliary bridge and scout roles may be filled by a variety of integrated positioning, sensing and communications systems. We can also expect that future computing, communications and networks will converge, and technology will be increasingly integrated, compatible and interoperable. Pressures for international standardization and open systems will leave their mark on new technology, and the marketplace will show increasing impatience with proprietary, non-interoperable technology. These technology trends, optimistically, might facilitate the development of improved and reliable organizational structures, cultures and artifacts (e.g., decision making, communications).

Future wearable technology may also contribute to the development of improved organizational structures:

> *A person's computer will be worn, much as eyeglasses or clothing are worn, and interact with the user based on the context of the situation. With heads-up displays, unobtrusive input devices, personal wireless local area networks, and a host of other context-sensing and communications tools, the wearable computer can act as an intelligent assistant, whether it is through a Remembrance Agent, augmented reality, or intellectual collectives (http://www.media.mit.edu/wearable).*

As technology augments—extends the reach and capabilities of—operators, communications in the future may be significantly changed. Future bridge and navigation systems will be able to automatically communicate with other vessels and shore stations to transmit regularly scheduled information and logistical and administrative data, and to run simulations to prepare for arrival or cargo discharge. These capabilities extend beyond our vision of AIS, and include capabilities to jog an operator's memory; provide additional sensing capabilities; help with navigation, geographic, face or pattern recognition; and automatically schedule and support logistical needs as part of an enterprise resource planning capability. With the addition of augmented reality, the mariner will be able to see important, individually tailored information about navigation, communication, cargo planning, arrival and logistical information, which can considerably affect the nature of open, shared communication requirements.

Future technologies can filter communications, sensing important and unimportant information in a particular context. These context-sensing and filtering capabilities of future technology will play an important role in augmenting the operator's capabilities and assisting us with difficulties and overloads that we have as human information processors— problems with memory, perception, recall, recognition and attention [Ref. 88].

Future technology can also assist in the development of organizational cultures that foster trust, as technologies can be personalizable, working for individual operators, establishing a trust and transparency relationship that is lacking in current technology. Current navigation, command and control and emergency response systems work for many operators, and are often configured for a particular operator (the master, the pilot) or for everyone – the least common denominator. Future technology can be individually tailored, portable, display-able anywhere, designed to facilitate, enhance and work for an individual operator. New trust relationships between operators, and between operators and technology, may develop because the operator can trust the technology in ways different from the situation of today: because it belongs to them, because interaction with the technology provides important, individually tailored information, and because the interaction and operation is understandable.

In order to enjoy these advantages, future technology must demonstrate significant advances in security and privacy, as well as demonstrate sophisticated context-sensing capabilities. Context awareness requires knowledge of the operator's environment, goals, tasks and responsibilities. That awareness is gained through sensing and interpreting data from the operator and the operator's environment. Storing and protecting such knowledge and information for the operator, for a vessel or tug, for a shipping or tug company, and for port states is an important issue that future technology must address.

As decision making is increasingly distributed to the operational level, we can expect to see greater proliferation of interfaces that reflect that migration. Smart skin technology is one such example: smart skin technology is a network of thin sensors painted on or applied to surfaces, with distributed computing, communications, sensors and interfaces. With these interfaces, navigation, command and control or emergency response system displays need not be desktop or computing displays. Instead, those interfaces can move with the operator, and can appear on all types of surfaces. These "skins" may take the form of gloves, vests, glasses, contact lenses, and/or embedded chips, or may be dynamically "painted" on bulkheads. Coupled with advances in convergence (consolidated computing, communications and control technology), smart skins offer opportunities to reconfigure the tasks of navigation, command and control, and emergency response so that the decision maker has the requisite information in real time and on appropriate display surfaces.

Microminiaturization, microelectronic mechanical systems (MEMS) and nano-technology will also leave their mark on future bridge and navigation systems, particularly in equipment and component monitoring, diagnosis and troubleshooting systems, and in vessel housekeeping systems and tasks [Ref. 7]. This suggests that tug escort roles of scout or auxiliary bridge may not exist in the future: they may be combined with other vessel management and control activities; they may be supervised by a combination of automated and human systems; and/or they may be assumed by new MEMS or nanotechnology devices. Visions of this type can be seen in the architecture and control systems of next generation naval vessels being deployed within the next decade. Thus, future navigation, command and control, and emergency response systems may be misnomers. These activities may be subsumed by a vessel architecture that encompasses a variety of vessel management and control activities.

Table 9-2 summarizes the technologies and topics identified as alternatives to the functional requirements provided by tug escorts with scout and auxiliary bridge responsibilities. The next section provides some caution with respect to wholesale adoption of such alternatives.

Table 9-2: Tug as Scout and Auxiliary Bridge Functional Requirements Mapped to Alternatives

Requirements	Alternatives
Navigation requirements	• Electronic charts • Integrated bridge systems • Knowledge-based systems • Embedded intelligent systems
Command and control requirements	• Intelligent collision avoidance systems • *Intelligent ship* projects • Integrated vessel control systems
Real-time and emergency response requirements	• Vessel traffic systems (VTSs) • Automated identification systems (AIS)
Organizational structure requirements	• Embedded intelligent systems • Intuitive user interfaces • Convergence technology • Wearable technology • Augmented reality, smart skins • Microminiaturization and nanotechnology

9.4 CAUTIONS

With the proposed alternatives comes the potential for old and new problems. As technology is deployed, mariners may in fact be overloaded with sensory information. There are also several problems with embedded intelligent systems that need to be addressed before these technological advances contribute more fully to enhance the safety in the marine transportation system [Refs. 74 & 76]. The issue of the degree to which technological aids can supplant or supplement human decision making is open to debate. The accuracy of the information provided, especially in the case of electronic charts, is still not assured to date as internationally accepted standards for uniform data transfer and data representation evolve.

"The seduction of safety" is a phrase apparently coined by the International Electrotechnical Commission (IEC) and used as early as 1999 as a shorthand means to express the sometimes false sense of precision and completeness conveyed to mariners by electronic navigational displays. Problems described by this phrase stem from such things as failure to appreciate errors inherent in such systems and accepting as reality the information they yield without cross-checking with other sources. The resulting dangers were recognized, for example, in the investigation following a 2000 collision between two ships in Canadian waters, as shown by the following quotation from the subsequent report [Ref. 102].

> *Given the immediate goal of passing the "LADY SANDALS," the OOW focused on the apparently precise representation of the area provided by the ECS [electronic chart] system, and did not appreciate the variance between its representation and the visual cues.*

The NTSB report on the *Royal Majesty* provides an additional example of this [Ref. 77].

Another potential area of concern is the issue of "stand-alone presentation of information," which refers to the situation in which mariners must draw and correlate data from a number of independent sources to develop information for decision making—typically a combination of visual cues, one or more radars, paper and electronic charts (ECDIS or ECS), conventional instruments such as compass, speed log, communications, machinery, instrumentation, alarm panels, AIS, embedded intelligent systems, 'smart skins' and the like. Mariners must not only correlate the data provided by these diverse sources but also reconcile differences between the various inputs and determine what is valid within a safety- and time-critical period.

In short, there are a number of alternatives to tug escorts that currently provide scout and auxiliary bridge functions to tankers. Caution should be exercised and functional task analyses performed before recommending adoption of any of the alternatives.

10 RISK ASSESSMENT

The central question for this study is whether there are potential modifications to the Washington State tanker escort requirements that recognize the safety enhancements of the new double-hull, redundant-system tankers, while maintaining system safety for the area currently covered by Washington's tug escort requirements at a level equal to or greater than that associated with double-hull, non-redundant tankers escorted in accordance with RCW 88.16.190 and current escort practice as it has evolved to comply with both Washington State and Federal law.

Thus, the criterion metric for any potential rule modification is that the resulting system must remain as safe as or safer than that afforded by the current system with single-screw double-hull tankers.

This section describes the calculation of oil-spill risk and provides probabilistic oil outflow for the evaluated tankers. Thus it addresses the central question for this study.

10.1 RELATIVE INCIDENT RATE PROBABILITIES

10.1.1 International and U.S. Data

A number of prior studies that developed incident probabilities have been reviewed. Some provide the data directly, and others have been combined by Herbert Engineering Corporation to develop the required information.

a. ABS Quantitative Risk Assessment Model for Tankers [Ref. 13]: ABS has developed a quantitative risk assessment tool for application to the classification of marine vessels and offshore structures. The example model developed is for a TAPS trade tanker. Probabilities of loss of propulsion, loss of steering, and of loss of propulsion and steering at the same time were developed for a single engine system and a twin engine, single shaft system. In this study loss of propulsion and steering together derives from a loss of normal shipboard power from the high voltage switchboards through the emergency switchboard.

   The estimated frequencies for the events are presented in terms of events per year. These are converted into events per hour assuming 6000 operational hours per year. The failure rates for the single engine tanker are shown in the following table.

Table 10-1: ABS QRA Single Engine Tanker Estimated Failure Rates

Incident	Probability per hour
Loss of propulsion	8.4×10^{-5}
Loss of steering	5.6×10^{-6}
Fire initiation	2.1×10^{-6}
Structural Failure	1.1×10^{-6}
Loss of propulsion and steering	8.8×10^{-7}
Explosion	1.6×10^{-9}

Based upon these data the total probability of propulsion loss is the sum of the two incident probabilities and equals 8.5×10^{-5} per hour. Similarly, the total probability of steering loss is 6.5×10^{-6} per hour.

This study also provided data on fire and explosion rates. However, these rates were not restricted to events located in areas that would compromise propulsion or steering.

b. An Introduction to ABS Guide for Propulsion Redundancy [Ref. 2]): ABS has developed failure rates for *individual components* of shafting equipment and diesel main engine systems based upon data developed by the Ship Reliability Investigation Committee (SRIC), Japan, over the period of 1982-1993, on 231 vessels of various types, showing the failure rates of machinery. These data have been used here to develop the failure rate for the combined system based upon a series system configuration, which puts the failure rate for a single screw propulsion system at 1.0×10^{-3} per hour.

c. Scandinavian Industry Consortium Study [Ref. 97]: A consortium including DNV, Finnish National Board of Navigation, Industrial Insurance, Kvaerner Masa-Yards, Neste Shipping, Wartsila Diesel and Wartsila Propulsion evaluated the benefits of redundant ship machinery using a 90,000 dwt tanker as an example. Information on mean time to failure (MTTF) and mean time to repair (MTTR) data are presented for various propulsion system options.

Utilizing this information, the failure frequency for the various components can be estimated. For example, the failure rate for the low speed propulsion engine is 1/3500 failures per hour.

For a system consisting only of independent components in series, the overall failure probability for one hour is 1 minus the probability of all components not failing. Based upon the component failure rates provided in the study HEC has developed system failure rates. For a low speed diesel, single screw system this results in a probability of failure per hour of 3.3×10^{-4}.

This study also provides estimated rates of steering loss and fire/explosion in the engine room, based on statistical data from 1976 through 1994. The steering incidents included only serious incidents – those resulting in collision, allisions, grounding or damage to hull equipment. The fire/explosion events are those occurring in the engine room with the ship underway, which disable the vessel or lead to constructive loss. The published incident rates are as follows:

Steering	.003 serious ship incidents per ship year
Fire/Explosion	.003 serious ship incidents per ship year

Assuming 6,000 operating hours per year, the incident rates per hour are as follows:

Steering	5.0×10^{-7} serious incidents per hour
Fire/Explosion	5.0×10^{-7} serious incidents per hour

d. Prince William Sound Risk Assessment [Ref. 15]: In the referenced study, drift groundings were simulated. In that study "Mechanical Breakdown Frequencies for Tankers" were utilized. These data can be interpreted as being based upon expert opinion rather than documented failure rates. The base case data presented are:

Propulsion	1.2×10^{-5} breakdowns per nm
Steering	5.4×10^{-6} breakdowns per nm

If a vessel speed of 12 knots (as used in that study) is assumed, these can be converted into failures per hour as:

Propulsion	1.5×10^{-4} breakdowns per hour
Steering	6.5×10^{-5} breakdowns per hour

The study used a combined rate of failure of 2.1×10^{-4} breakdowns per hour.

e. UK Coast Guard Study [Ref. 30]: This study, performed by DNV, used their CRASH simulation software to model drift groundings. The frequency of mechanical breakdowns (steering or propulsion) used was 2.0×10^{-5} per hour. As this is 1/10 the number developed in the PWS study performed by the same group, we suspect one of the two is in error. This report also provides alternative data for a frequency of *serious* casualties (primarily breakdowns) due to machinery damage: 5.3×10^{-7} per hour. As noted in the study, breakdowns do not necessarily lead to serious casualties.

f. USCG CASMAIN Data: The U.S. Coast Guard CASMAIN database was accessed for casualty and accident data related to steering gear failures, propulsion failures and fire/explosions.

Between 1992 and 2000, there were a total of 230 steering failures reported for tankers underway in U.S. waters. This translates to a steering failure incident rate of approximately 2.9×10^{-5} per hour.

Between 1992 and 2000, there were a total of between 326 and 660 propulsion system casualties reported for tankers underway in U.S. waters. This translates to a loss of propulsion incident rate of approximately 4.3×10^{-5} to 8.7×10^{-5} per hour. The scatter is due to the difficulty in assessing, based upon the casualty description, whether the reported incident led to actual loss of propulsion. For the purposes of this study an average rate of 6.5×10^{-5} per hour is used.

Between 1992 and 2001, there were a total of 25 engine room fires/explosions in tankers underway in U.S. waters. This translates to an incident rate of approximately 3.3×10^{-6} per hour. It is estimated that roughly 1/3 of these incidents results in loss of propulsion, corresponding to a rate of 1.1×10^{-6} per hour.

10.1.2 Puget Sound Incident Data

The Puget Sound Vessel Traffic Service provided access to files of over 630 incident reports dating back to 1985. A team of Glosten Associates read through each paper file and entered data into a collection database for incidents of interest. Electronic copies of files were available for incidents occurring in 2001 and later. Incidents related to issues such as improper VHF frequency, radio monitoring problems, failure to make required reports and advanced reporting requirements were not included for consideration. A summary of incident tables for the Puget Sound VTS can be found in Appendix B.

Based on 16,655 tanker transits between 1996 and 2003, the following can be derived.

P(Loss of Steering | Tanker) on a given transit = 6/16655 = 0.00036
P(Loss of Propulsion | Tanker) on a given transit = 8/16655 = 0.00048

The equivalent failure rates per hour, based upon an average 6 hours per transit, are:

Propulsion	8.0×10^{-5} breakdowns per hour
Steering	6.0×10^{-5} breakdowns per hour

10.1.3 Summary of Puget Sound, U.S. and International Data

Steering Gear and Propulsion System:

Table 10-2 provides the average failure rates per hour from the various sources.

The Consortium report gives an incident rate of 5.0×10^{-7} serious incidents per hour for loss of steering. However, this rate is for failures leading to major accidents, and is therefore significantly lower than the other probability failure rates shown below and is excluded from the averaging.

The failure rate for loss of propulsion based upon ABS Guide for Propulsion Redundancy data [Ref. 2] uses an indirect assessment of the combined system failure. It is significantly higher than the others and is excluded from the averaging of failure rates.

An average rate has been developed with the most extreme outlier data removed. Even so, the range in data is significant as shown in the maximum/minimum ratios.

Table 10-2: Averaged Failure Rates for Propulsion and Steering

Averages	PS Incident	ABS QRA	ABS Guide	Consortium	PWS RA	USCG	Average	Max/Min	Per Transit
Loss of steering	4.50E-05	6.50E-06		5.00E-07	6.50E-05	2.90E-05	3.64E-05	10	2.91E-04
Loss of propulsion	6.00E-05	8.50E-05	1.00E-03	3.30E-04	1.50E-04	6.50E-05	1.38E-04	6	1.10E-03
					not included in average, or max/min ratio				

As shown in Table 10-2, the incident rates presented in the various studies vary from maximum to minimum by about an order of magnitude. The data from the U.S. sources (i.e., Puget Sound and USCG incident data) show relatively good agreement despite inconsistencies in the databases (see Section 10.1.5).

All are likely optimistic, as they are based on historical data which tend to be under-reported.

It is interesting to note that the failure rates for loss of propulsion taken from the Puget Sound and USCG databases are: a) remarkably similar, and b) approximately one-fifth the rate from the other sources. It is tempting to associate this with the make-up of the fleet in U.S. waters databases, having as it does a higher percentage of U.S.-flag and -owned vessels compared with the internationally based data. However caution is recommended before making this conclusion as the uncertainty in the data is large (again see Section 10.1.5).

<u>Fire/Explosion:</u>

The USCG data analysis produced an incident rate of fire/explosions in engine rooms of tankers underway, sufficient to disable machinery operation, of 1.1×10^{-6}. The Consortium study gave a fire/explosion rate in engine rooms of vessels underway of 5.0×10^{-7} incidents per hour. It should be noted that the Consortium data are based on serious incidents that permanently disable the vessel.

It is recognized that fire/explosion is a major cause of loss of life and property at sea. However, the probability of fire/explosion in the engine room is very small in comparison with the likelihood that mechanical failure will disable the propulsion system.

10.1.4 <u>Failure Rate Per Transit</u>

Assuming an average transit time of six hours, the average values per transit are as follows:

<u>Single Propulsion/Steering System</u>

P(Loss of Steering | Tanker) on a 6 hour transit	2.3×10^{-4}
P(Loss of Propulsion | Tanker) on a 6 hour transit	5.8×10^{-4}

Loss of steering is consistently about one order of magnitude less frequent than loss of propulsion.

A redundant engine system can be represented by two parallel systems of series linked components. The overall failure probability is the product of the probability of either one failing. If each side is fully independent, the probability of failure of both systems during a transit is:

<u>Redundant Propulsion/Steering System</u>

P(Loss of Steering | Tanker) on a 6 hour transit	7.8×10^{-8}
P(Loss of Propulsion | Tanker) on a 6 hours transit	3.8×10^{-7}
P(Loss of Propulsion & Steering on opposite sides)	9.6×10^{-8}

The frequency of a second failure within a specified time period after the first failure is calculated using the following formula.

$$P(A,B) = \{1 - e^{-\lambda_a T_a}\}\,\{1 - e^{-\lambda_b T_b}\}$$

where *P(A, B)* is the probability of two failures *A* and *B*; λ_a, λ_b are the failure frequency rates for *A* and *B* (in incidents/hr); and T_a and T_b are the time intervals in which the failure occurs. In the calculations shown above, T_a and T_b are 6 hours (the nominal average transit time for a tanker in Puget Sound).

There are a limited number of events that could render inoperative both sides of a redundant-system. An explosion can damage the centerline bulkhead between the engine rooms or steering gear rooms, or a collision or grounding could penetrate the bulkhead. Other possibilities are related to human error. For instance, if the watertight doors in the centerline bulkhead between engine rooms were left open, flooding or fire could disable both engine rooms. If the main switchboards in each engine room were left cross-connected, a blackout would affect both plants. Such practices are in violation of standard operating procedures, particularly when maneuvering in restricted waters.

10.1.5 <u>Uncertainty and Biases in Incident Rate Probabilities</u>

As described above, there is a wide scatter in the estimates for failure rates. This uncertainty must be accounted for in evaluating the risks of the alternative approaches.

When reviewing failure rates based upon historical data or design studies, one must recognize the limitations in the quality and purpose of the databases in question.

Use of Availability Data

Some of the data are based upon availability studies for design projects. Availability is a key part of the effectiveness of a propulsion or steering system for normal operations. Availability is defined using mean time to failure (MTTF) and mean time to repair (MTTR) data. Availability “A” is defined by:

$$A = \frac{MTTF}{MTTF + MTTR}$$

MTTF can be used to estimate failure rates. However, failure in assessing availability may not be a failure that immediately takes down the system in question. For example, a bearing overheating may be considered a failure from a design availability perspective but may be tolerable for grounding or collision avoidance during passage through Rosario Strait.

Use of Historical Data

Some of the data are based upon historical data, i.e. state and federal databases of incidents and other commercial and international sources. The use of these databases has several potential sources of uncertainty or bias including:

- Inconsistency between databases. For example, steering system failures in the Washington State incident database should be a subset of the USCG database. However, only one of the six events in the State database is included in the USCG database.

- Combination of different types of data. USCG casualty databases have been combined with estimates of transit miles for vessels in U.S. waters. There are significant approximations in this approach.

- Judgment by the operator that the incident is insignificant and does not require reporting. For example, a short term loss of propulsion while far out at sea (say 5 minutes) may not be reported, yet events of this nature are significant while transiting the subject waters and influence the failure rate statistics.

- Sparseness of the database. Incidents are rare and small numbers of additional events significantly affect the statistics.

- Vessel type. Not all the database information is tanker-specific.

- Regional bias. Failure rates in U.S. waters may be different from international data due to the higher percentage of U.S. flag vessels.

- Historical databases reflect existing design and operational practices that have or may change. For example, there has been significant reduction in oil spills since relatively soon after the introduction of OPA 90. The causes of this reduction are probably but not conclusively related to operational practices, yet casualty and mechanical breakdown data often include significant data from earlier periods.

  Another example of the change over time is shown in the following figure derived from the SRIC database [Ref. 55] that underlies some of the ABS data. This also shows a significant drop in the failure rates after 1990.

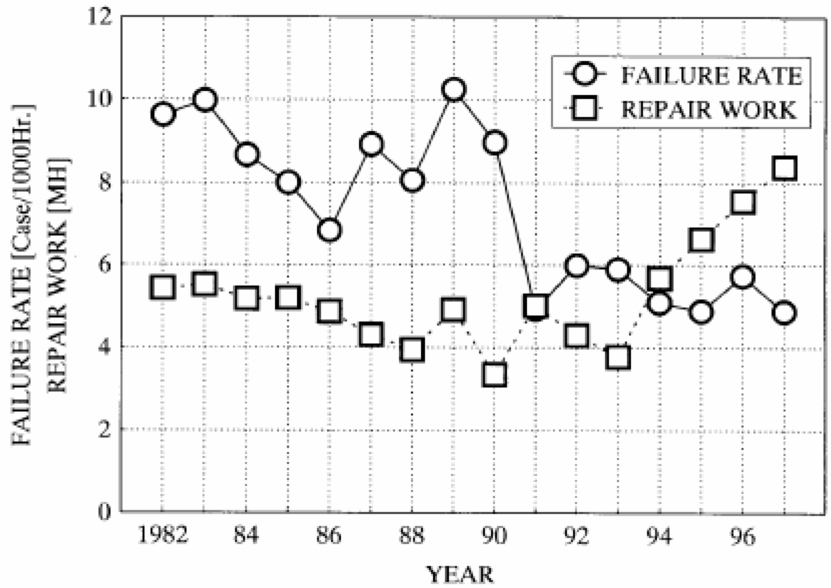

Figure 10-1: Failure Rate and Repair Work Changes over Time [Ref. 55]

10.2 CONDITIONAL PROBABILITIES OF GROUNDING

The Puget Sound channel width statistics were developed by The Glosten Associates. Three regions are considered: North Puget Sound, including Rosario Strait to Cherry Point; Guemes Channel; and Puget Sound South, including Admiralty Inlet to Commencement Bay. Figures 11-2 through 11-4 show these three regions. Table 10-3 summarizes the Puget Sound channel width statistics. Table 10-4 indicates that grounding can be averted when the vessel transits a given waterway at the appropriate speed and the proper emergency response maneuver is performed. Since Guemes Channel is narrow compared with other areas of concern, vessels must proceed slowly.

Table 10-3: Channel Width Statistics for Puget Sound Waterways

	Zone 2: Rosario Strait		Zone 2a: Guemes Channel		Zone 2b: Rosario to Viti Rocks		Zone 2c: Viti Rks to Willaim Pt.		Zone 2d: William Pt. to anchorage		Zone 3: Puget Sound	
Limit:	Transfer Distances Measured to 10 Fathom Contour		Transfer Distances Measured to 5 Fathom Contour		Transfer Distances Measured to 10 Fathom Contour		Transfer Distances Measured to 10 Fathom Contour		Transfer Distances Measured to 10 Fathom Contour		Transfer Distances Measured to 10 Fathom Contour	
	(feet)	(n.m.)	(feet)	(n.m.)	(feet)	(n.m.)	(feet)	(n.m.)	(feet)	(n.m.)	(feet)	(n.m.)
Max	108,750	17.90	16,680	2.75	39,690	6.53	109,840	18.08	21,440	3.53	36,010	5.93
Average	11,710	1.93	4,540	0.75	10,650	1.75	12,190	2.01	7,940	1.31	10,560	1.74
Median	9,520	1.57	3,170	0.52	7,370	1.21	6,740	1.11	7,870	1.30	8,800	1.45
80% greater than	5,870	0.97	1,590	0.26	5,440	0.90	4,580	0.75	3,380	0.56	6,480	1.07
90% greater than	4,730	0.78	1,350	0.22	3,940	0.65	3,450	0.57	2,560	0.42	5,630	0.93
95% greater than	3,370	0.55	1,190	0.20	3,140	0.52	2,940	0.48	2,400	0.39	4,890	0.80
98% greater than	2,770	0.46	1,120	0.18	2,740	0.45	2,370	0.39	1,920	0.32	4,210	0.69
99% greater than	2,550	0.42	1,100	0.18	-	-	-	-	-	-	3,920	0.65
Min	950	0.16	1,060	0.17	2,490	0.41	1,770	0.29	1,810	0.30	3,600	0.59

Table 10-4: Simulation-Predicted Off-Track Transfer Distances as a Function of Speed, Rudder Angle and Maneuver. Comparisons are Made to **95th** Percentile Channel Width.

Tranist Speed at Time of Rudder Failure [knots]	**Rudder Failure Angle** [deg]	Emergency Response **Maneuver**	**Off-Track Distance**	95th Percentile Grounding Averted		
				Rosario Strait	**Guemes Channel**	**Puget Sound** (Admiralty Inlet to Tacoma)
4	5	ASSIST	720'	**YES**	**YES**	**YES**
4	5	OPPOSE	20'	**YES**	**YES**	**YES**
4	10	ASSIST	700'	**YES**	**YES**	**YES**
4	10	OPPOSE	30'	**YES**	**YES**	**YES**
4	20	ASSIST	660'	**YES**	**YES**	**YES**
4	20	OPPOSE	90'	**YES**	**YES**	**YES**
4	35	ASSIST	600'	**YES**	**YES**	**YES**
4	35	OPPOSE	330'	**YES**	**YES**	**YES**
Solution at 4 knots >>>>>>>>>>>>>>>				**YES**	**YES**	**YES**
5	5	ASSIST	1,160'	**YES**	**YES**	**YES**
5	5	OPPOSE	30'	**YES**	**YES**	**YES**
5	10	ASSIST	1,120'	**YES**	**YES**	**YES**
5	10	OPPOSE	90'	**YES**	**YES**	**YES**
5	20	ASSIST	1,010'	**YES**	**YES**	**YES**
5	20	OPPOSE	580'	**YES**	**YES**	**YES**
5	35	ASSIST	860'	**YES**	**YES**	**YES**
5	35	OPPOSE	2,610'	**YES**	NO	**YES**
Solution at 5 knots >>>>>>>>>>>>>>>				**YES**	**YES**	**YES**
6	5	ASSIST	1,620'	**YES**	NO	**YES**
6	5	OPPOSE	70'	**YES**	**YES**	**YES**
6	10	ASSIST	1,530'	**YES**	NO	**YES**
6	10	OPPOSE	370'	**YES**	**YES**	**YES**
6	20	ASSIST	1,350'	**YES**	NO	**YES**
6	20	OPPOSE	3,550'	NO	NO	**YES**
6	35	ASSIST	1,110'	**YES**	**YES**	**YES**
6	35	OPPOSE	4,710'	NO	NO	**YES**
Solution at 6 knots >>>>>>>>>>>>>>>				**YES**	**NO**	**YES**

Tranist Speed at Time of Rudder Failure [knots]	**Rudder Failure Angle** [deg]	Emergency Response **Maneuver**	**Off-Track Distance**	95th Percentile Grounding Averted		
				Rosario Strait	**Guemes Channel**	**Puget Sound** (Admiralty Inlet to Tacoma)
8	5	ASSIST	2,450'	**YES**	NO	**YES**
8	5	OPPOSE	630'	**YES**	**YES**	**YES**
8	10	ASSIST	2,280'	**YES**	NO	**YES**
8	10	OPPOSE	5,580'	NO	NO	NO
8	20	ASSIST	1,940'	**YES**	NO	**YES**
8	20	OPPOSE	7,700'	NO	NO	NO
8	35	ASSIST	1,560'	**YES**	NO	**YES**
8	35	OPPOSE	5,680'	NO	NO	NO
Solution at 8 knots >>>>>>>>>>>>>>>				**YES**	**NO**	**YES**
10	5	ASSIST	3,220'	**YES**	NO	**YES**
10	5	OPPOSE	7,030'	NO	NO	NO
10	10	ASSIST	2,920'	**YES**	NO	**YES**
10	10	OPPOSE	8,940'	NO	NO	NO
10	20	ASSIST	2,420'	**YES**	NO	**YES**
10	20	OPPOSE	8,290'	NO	NO	NO
10	35	ASSIST	1,920'	**YES**	NO	**YES**
10	35	OPPOSE	5,900'	NO	NO	NO
Solution at 10 knots >>>>>>>>>>>>>>>				**YES**	**NO**	**YES**
12	5	ASSIST	3,860'	NO	NO	**YES**
12	5	OPPOSE	9,370'	NO	NO	NO
12	10	ASSIST	3,420'	NO	NO	**YES**
12	10	OPPOSE	9,410'	NO	NO	NO
12	20	ASSIST	2,790'	**YES**	NO	**YES**
12	20	OPPOSE	8,210'	NO	NO	NO
12	35	ASSIST	2,210'	**YES**	NO	**YES**
12	35	OPPOSE	5,940'	NO	NO	NO
Solution at 12 knots >>>>>>>>>>>>>>>				**NO**	**NO**	**YES**

All cases model a Suezmax double-hull single-screw tanker loaded to 125,000 dwt and an untethered RCW minimum compliance 6,250 hp conventional tug, in calm conditions.

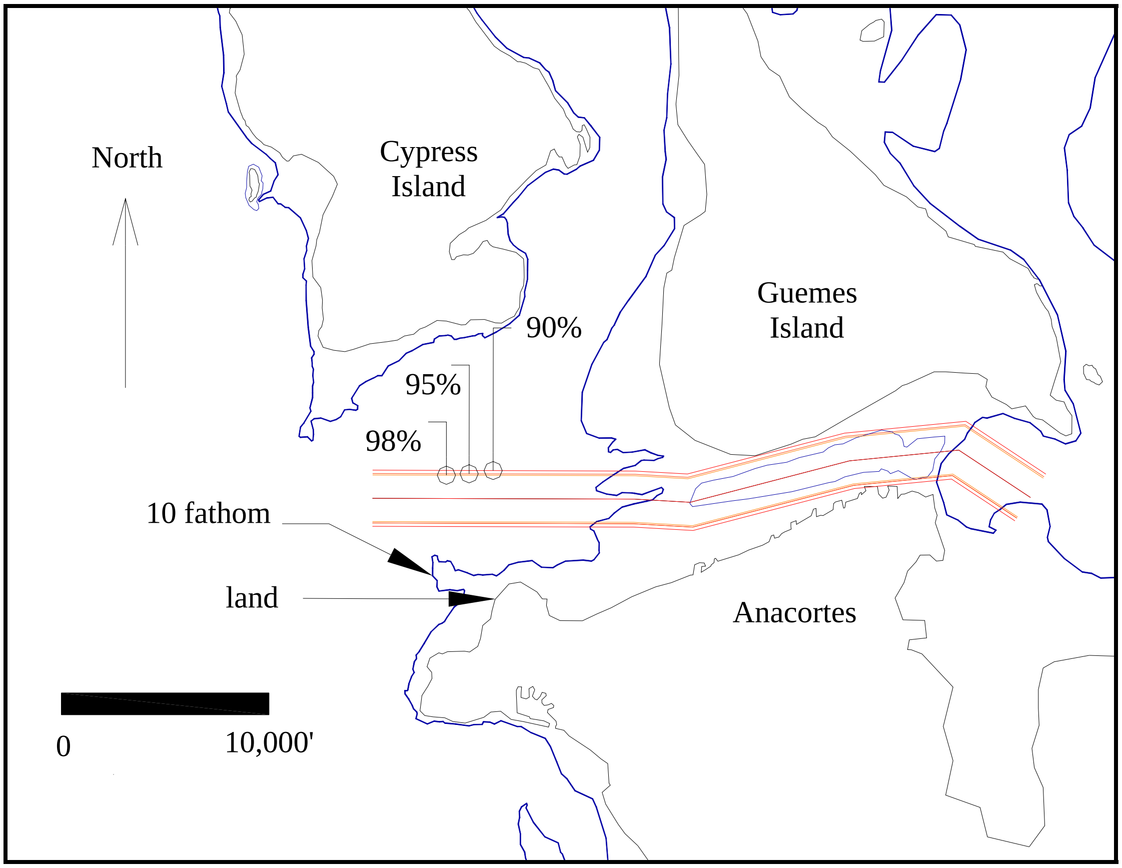

Figure 10-2: Guemes Channel Off-Track Clearances. (10-fathom Contour Shown on Map. Calculations for 5-fathom Contour.)

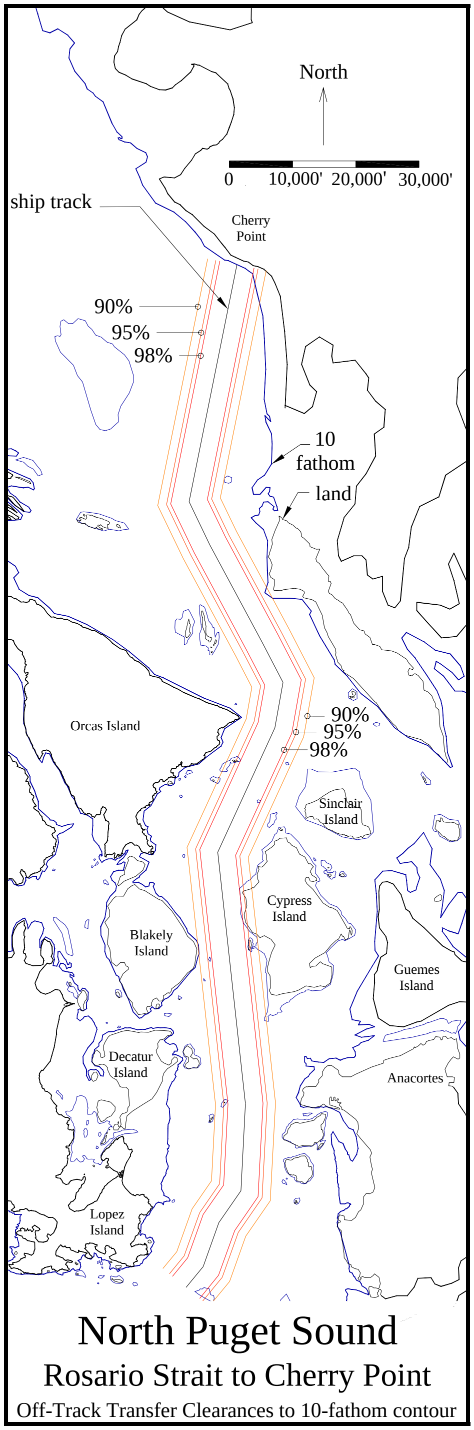

Figure 10-3: North Puget Sound Off-track Distances to 10-fathom Contour

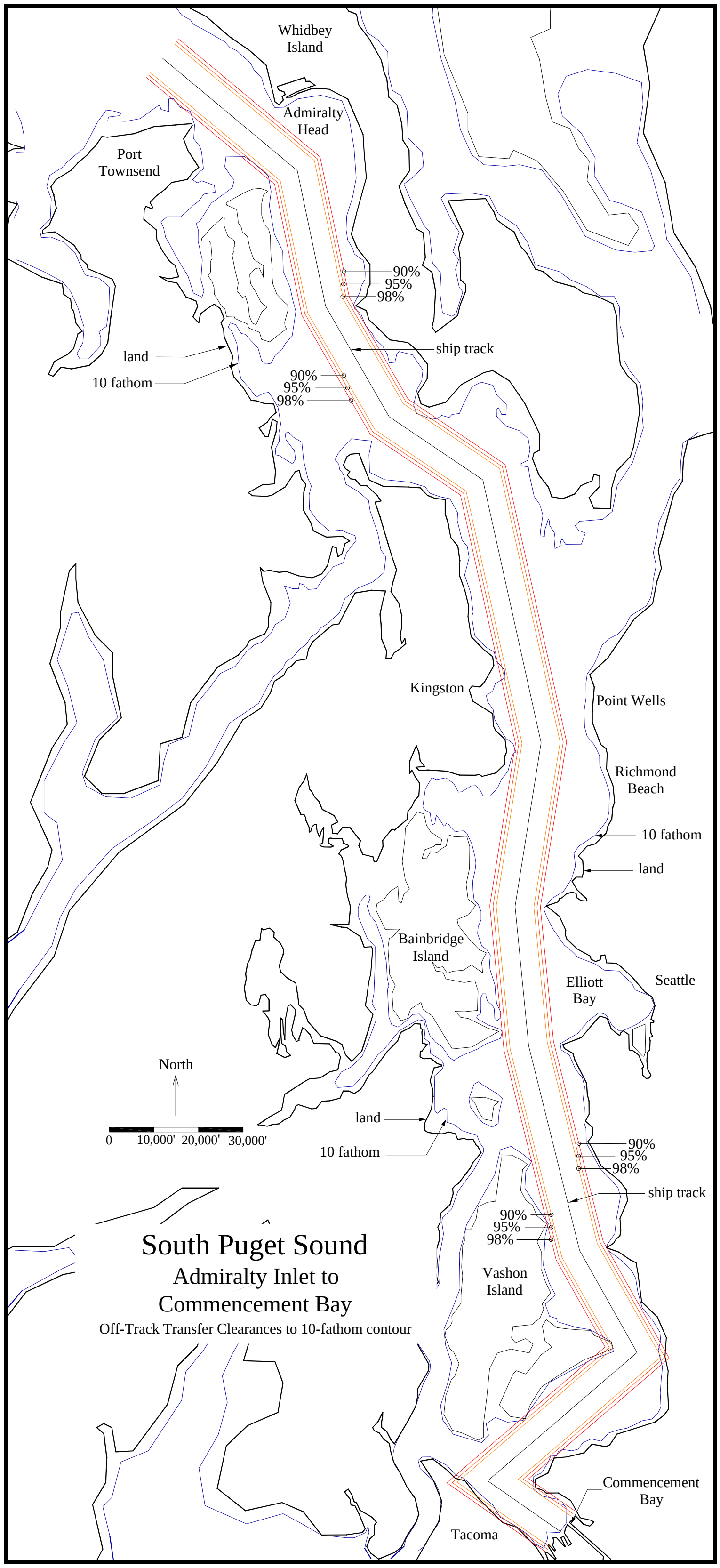

Figure 10-4: South Puget Sound Off-track Distances to 10-fathom Contour

10.3 PROBABILISTIC OIL OUTFLOW ANALYSIS

10.3.1 Baseline Probabilistic Oil Outflow for an IMO MARPOL Minimally Compliant Double-Hull Tanker of the Largest Size Allowed in Puget Sound Waters Following Grounding

The primary purpose of the grounding/oil outflow analysis is to compare the risk between the single screw, escorted double-hull vessels with the redundant double-hull vessels with no escorts. This section considers the oil outflow portion of the analysis and assumes the vessel has grounded. The overall approach uses damage statistics from tanker groundings used by IMO in the regulatory assessment of tanker oil outflow to develop a suite of damage scenarios with associated probabilities of occurrence. Each damage scenario is evaluated for oil outflow and two key parameters are calculated. These are the probability that no oil will be spilled (this is generally known as the probability of zero outflow, or P_0), and the weighted average or mean amount of oil spilled (in m^3). In the U.S., P_0 is considered a key parameter, while the trend in international regulations is to primarily consider the mean outflow.

The overall dimensions and cargo arrangements of a single screw, double-hull vessel and redundant double-hull vessel are similar enough that the oil spill parameters can be considered the same for both vessel types. Thus the consequence portion of the risk is identical for the two systems, and the differences in risk will be due to differences in the probability of grounding.

However, to establish the change in risk, the consequence of grounding (first in terms of oil spillage) must be evaluated.

The choice of the baseline ship used establishes the amount of oil potentially spilled. Washington State (RCW 88.16.190) has a maximum deadweight limit of 125,000 LT east of New Dungeness Light. The intent is to limit the maximum size of an oil spill. Thus the baseline ship is a tanker of 125,000 tons dwt.

Initially, the baseline ship considered was to be a vessel that is minimally compliant with the existing IMO Regulations. The governing regulation is IMO 13F. This would result in a tanker with 2 m double sides and slightly deeper double bottoms (approximately 2.2 m). The double bottom is deeper than minimum regulatory requirements for structural reasons. A theoretical tanker design was developed that meets the deadweight and regulatory requirements.

However, this tanker will not be built, as it would be considered uneconomical to construct a tanker optimized for Washington State trade but inefficient for other use. This is reflected in the designs of the redundant double-hull vessels now trading in Washington State. Both the *Endeavour* Class vessels operated by Polar Tankers and the *Alaska* Class vessels operated by ATC are larger vessels that have light loadlines that limit the deadweight to be compliant with State requirements. A non-redundant tanker built to trade in Washington State would also be configured this way. The tankers would be of approximately 150,000 dwt with a limited loadline. Tankers of this size fall into the Suezmax category of tankers, of which there are a few hundred single and double-hull ships world wide.

Suezmax tankers will be partially loaded to meet the State deadweight limits. Furthermore, Suezmax tankers built to trade into Washington State after 2006 will have to comply with the new IMO MARPOL Regulation 21 – "Accidental Oil Outflow Performance". This regulation calls for a greater level of subdivision than the current hypothetical outflow regulation. The 150,000 DWT vessel used as a model for the baseline ship meets the requirements of this new regulation.

a. Baseline Ship

Suezmax Class: This design is entirely double-hulled in way of the cargo block, configured as a 6 long by 2 wide cargo tank arrangement (Figure 10-6) with two slop tanks aft. The double bottom extends over the length of the cargo block with a depth of 2.5 m on centerline; the double sides are also 2.5 m wide. The ballast tanks extend from forepeak tank forward to the pump room just forward of the engine room. All ballast tanks have a J-tank configuration. The fuel oil tanks are within the engine room. The ship's main dimensions are:

Lbp = 260.4 m

B = 47.345 m

D = 23.673 m

T = 14.8 m

D/T = 1.60

On average her cargo tanks dimensions are:

l = 32.78 m

b = 21.17 m

d = 22.27 m

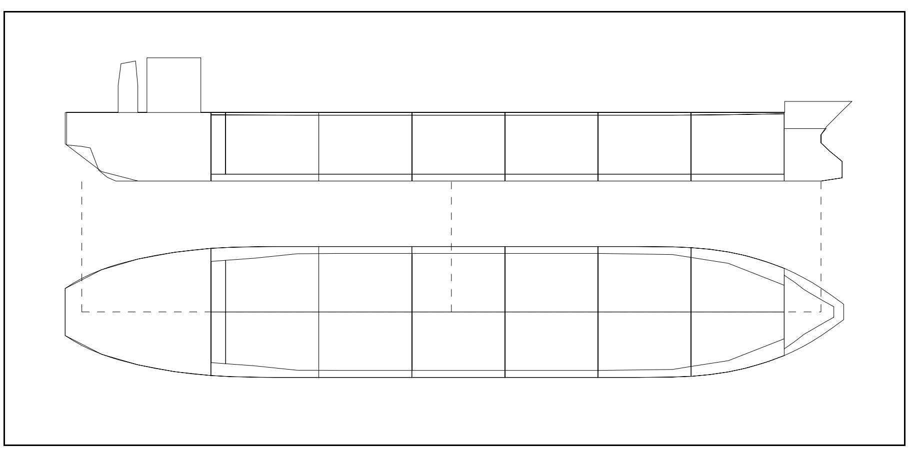

Figure 10-5: Suezmax Tanker

b. Probabilistic Oil Outflow Methodology

The procedures for probabilistic oil outflow are based upon the IMO Guidelines [Ref. 52] developed in association with Regulation 13F. The USCG uses this approach when evaluating alternatives to double-hull tankers or foreign flag double-hull tankers that do not explicitly meet OPA 90 requirements. Probabilistic analysis, whether it is for ship damage stability or oil outflow, is based on evaluating the cumulative probability of occurrence of an expected consequence (survival or quantity of outflow). It is typically formulated in terms of the following conditional probabilities:

- The probability that the ship will encounter damage
- The probability of the damage location and extent
- The probability of survival or expected consequences

Evaluation of all of these probabilities would constitute a fully probabilistic evaluation for a specific vessel on a specific route.

Both collision and grounding analyses are performed in the IMO approach. In this study the evaluation has been primarily directed at groundings.

The IMO Guidelines do not specifically deal with the probability of whether the ship will encounter damage. Instead, it is acknowledged that the risk does exist, and assumes that, in fact, the vessel has been involved in a casualty event significant enough to breach at least one compartment. The methodology deals exclusively with determination of the probability of damage extent (once damage has occurred) and calculation of the resulting consequences. A full description of the analysis can be found in Appendices C and D.

The IMO Guidelines provide probability information for the damage extents. These are presented in terms of probability density functions that are non-dimensionalized based upon ship principal particulars (LBP, beam and depth). The statistics are based upon casualties worldwide for tankers over 30,000 tonnes deadweight. The database pre-dates double-hull tankers.

The basic approach is to develop a set of damage scenarios or cases, each with an associated probability of occurrence (conditioned on the grounding having happened). For each damage case there is a possibility of oil outflow. A significant number of the cases will lead to no oil outflow and the total probability of these cases is referred to as the "*Probability of zero outflow*" or P_0. Typically this is about 0.8 or 80% for double-hull tankers (and about 10% to 20% for single-hull tankers). Secondly, the "*Mean*" outflow is computed by summing the oil outflow for each case weighted by the probability of the damage case. A third parameter is also computed: "extreme" outflow that is the weighted average of the upper 10% of all casualties.

The recently developed MARPOL Regulation 21, "Accidental Oil Outflow Performance," will go into force in 2006. This regulation uses a conceptual design approach to calculate mean outflow utilizing the same statistics, in order to assess the outflow performance of the tanker subdivision.

For groundings, both regulations include the effect of tidal change when evaluating oil outflow. The methodology assumes that the grounding could occur at any state of tide. Dropping tides create a larger relative pressure head on the oil remaining in the vessel leading to additional oil outflow. Based on tide ranges worldwide, the IMO 13F regulation specifies a weighted average of 0 m, 2 m and 6 m tide changes. The more recent Reg. 21 uses just two cases, 0 m and 2.5 m change reflecting a reassessment of the impact of the tide change.

c. Modifications to Methodology for Application to the Tanker Escort Study

Tides. IMO Regulation 21 differs from the original IMO implementation with respect to the treatment of tidal changes. Regulation 21 considers only two tide states, zero tide drop and 2.5 m tide drop, weighted 70% and 30% respectively, whereas Regulation 13F considered three tide states. Tidal ranges for Dungeness Point, Anacortes and Cherry Point were reviewed for 2004 and found to be about 2.4 m between MLLW and MHHW. The tidal changes assumed in Regulation 21 more closely represent the Puget Sound condition, and therefore are applied in this study.

Grounding only. As the purpose is to evaluate oil spillage given grounding, no collision evaluation was performed. However, groundings represent only part of the risk to the waterway and a comparison of escort requirements or vessels should recognize the role of collisions.

Consistent damage. The regulations, MARPOL 13F and the new regulation MARPOL 21, apply probability density functions for damage extent that are non-dimensionalized using the ship principal particulars (LBP, beam and depth). Thus, the assumed maximum vertical penetration during grounding will be larger for a ship with a greater depth. As Suezmax tankers operated in the State of Washington will not be loaded to the 125,000 dwt limit rather than to a full load condition as required for regulatory assessment, a slightly different approach was taken when comparing the baseline vessel to the *Endeavour* and *Alaska* Class redundant vessels. The assumption is that the depth of penetration is largely governed by the kinetic energy that needs to be absorbed and this is primarily based upon the mass of the vessel. As the Suezmax tanker and both the redundant ships are all the same deadweight, the same vertical damage extents have been applied to all three models evaluated in this study.

Statistics. Concurrent with this study, there are on-going efforts to update damage statistics. Two of these are the European Commission HARDER and POP&C projects. HEC has participated (either directly or via individual participation) in both. As the IMO damage statistics are more than a decade old, the HARDER data were reviewed to ascertain if the damage statistics have changed. The number of groundings of vessels in the size range has not increased enough to justify modifying the IMO statistics.

d. Loading Condition

The vessel is loaded to a 125,000 dwt condition. Cargo density has been chosen to match the Puget Sound loading condition for the *Endeavour* Class ship. The vessel is loaded to 98% in the cargo tanks with the exception of the No.1s, which are loaded to 65%, the No.5s at 77% and the slop tanks at 50%. Consumables are set at 50%. Both the *Endeavour* and *Alaska* Class redundant ships are loaded in a similar manner when entering Washington State waters. The draft is 14.8 m.

e. Results

Table 10-5: Probabilistic Oil Outflow Results for Baseline Ship in Groundings

SM 125 0 tide	**SM 125 2.5 tide**	**SM 125 Combined**
Probability of zero outflow = 0.844	Probability of zero outflow = 0.801	Probability of zero outflow = 0.831
Mean oil outflow = 1,005 m^3	Mean oil outflow = 1,891 m^3	Mean oil outflow = 1,271 m^3
Extreme (1/10)oil outflow = 8,452 m^3	Extreme (1/10)oil outflow = 15,452 m^3	Extreme (1/10)oil outflow = 10,552 m^3

10.3.2 Probabilistic Oil Outflow for *Endeavour* Class and ATC *Alaska* Class Double-Hulled Tankers Following Grounding

The *Endeavour* Class and the *Alaska* Class tankers are the redundant-system tankers currently sailing through the Puget Sound. Both designs are arranged with a double bottom and double sides in compliance with – and, indeed, well in excess of – the requirements of the OPA 90 and MARPOL regulations. In both cases, the deadweight has been restricted to 125,000 tons, equivalent to a draft of 16.15 m for the *Endeavour* Class and 14.45 m for the ATC *Alaska*.

This section compares the pollution prevention and mitigation performance of the *Endeavour* Class and the *Alaska* to the theoretical baseline tanker of the same dwt, herein referred to as SM 125. As described above, the SM 125 design meets the specific minimum requirements of the new IMO Regulation 21. The intent is to describe the behavior of the two ships with regard to oil outflow performance when subject to groundings.

a. Tanker Designs Analyzed

Endeavour Class: This design is entirely double-hull in way of the cargo block, configured as a 6 long by 2 wide cargo tank arrangement (Figure 10-6) with two slop tanks aft. The double bottom extends over the length of the cargo block with a depth of 3 m on centerline and the double sides are also 3 m wide. The ballast tanks extend from the thruster room forward to the pump room. All ballast tanks have a J-tank configuration. The fuel oil tanks are double-hulled, and located within the engine room. The ship's main dimensions are:

Lbp = 258.16 m
B = 46.2 m
D = 25.3 m
T = 16.15 m
D/T = 1.567

On average her cargo tanks dimensions are:

l = 31.68 m
b = 20.1 m
d = 22.3 m

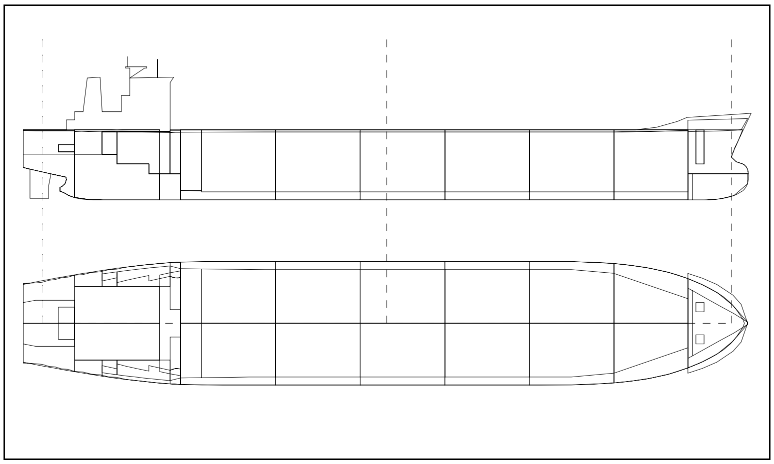

Figure 10-6: *Endeavour* Class

Table 10-6 Probabilistic Oil Outflow Results for *Endeavour* Class in Groundings

***Endeavour* 0 tide**	***Endeavour* 2.5 tide**	***Endeavour* Combined**
Probability of zero outflow = 0.862 Mean oil outflow = 880 m^3 Extreme (1/10)oil outflow = 7,736 m^3	Probability of zero outflow = 0.858 Mean oil outflow = 1,563 m^3 Extreme (1/10)oil outflow = 13,750 m^3	Probability of zero outflow = 0.861 Mean oil outflow = 1,085 m^3 Extreme (1/10)oil outflow = 9,450 m^3

<u>ATC Alaska</u>: This design is entirely double-hull in way of the cargo block, configured as a 6 long x 3 wide cargo tank arrangement (Figure 10-7) with two slop tanks aft. The double bottom extends over the length of the cargo block with a depth of 2.7 m on centerline and the double sides are also 2.7 m wide. The ballast tanks extend from the fwd peak to the pump room. All ballast tanks have a J-tank configuration. The fuel oil tanks are double-hulled, and located within the engine room. The ship's main dimensions are:

Lbp = 274.00m
B = 50.0 m
D = 28.0 m
T = 14.45 m
D/T = 1.938

On average her cargo tanks dimensions are:

l = 31.68 m
b = 15.00 m
d = 26.2 m

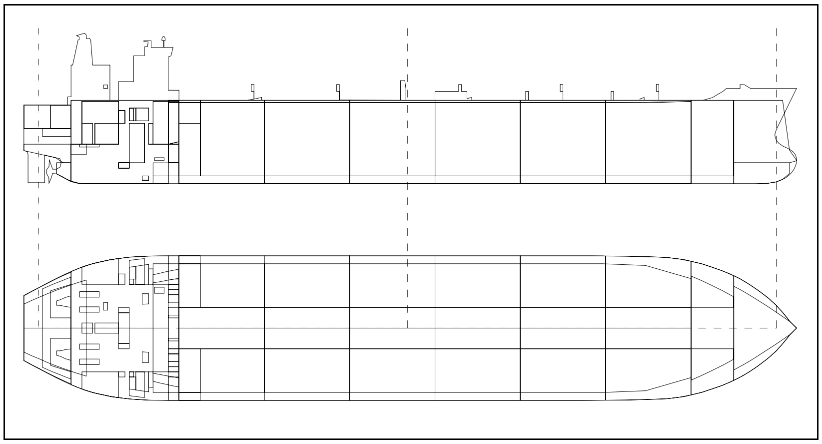

Figure 10-7: ATC *Alaska*

Table 10-7 Probabilistic Oil Outflow Results for *Alaska* Class in Groundings

***Alaska* 0 tide**	***Alaska* 2.5 tide**	***Alaska* Combined**
Probability of zero outflow = 0.831 Mean oil outflow = 1,791 m^3 Extreme (1/10)oil outflow = 14,776 m^3	Probability of zero outflow = 0.831 Mean oil outflow = 2,435 m^3 Extreme (1/10)oil outflow = 19,964 m^3	Probability of zero outflow = 0.831 Mean oil outflow = 1,984 m^3 Extreme (1/10)oil outflow = 16,332 m^3

10.3.3 Discussion of Probabilistic Oil Outflow for Baseline, *Endeavour* Class and ATC *Alaska* Class Double-Hulled Tankers

The oil cargo of these Suezmax sized tankers is approximately 142,700 m^3 and thus the mean outflows for each vessel are 0.9%, 0.8% and 1.4%, respectively, of the oil on board. The *Alaska* Class vessel's performance in this light load condition is a function of the relatively shallow draft combined with a relatively deep hull configuration. The depth over draft ratio for this vessel is 1.9 compared with 1.6 for the other vessels, leading to a greater head of oil when grounded.

It is appropriate to point out that when collisions are also considered, as in IMO Regulation 21, then the mean oil outflows for the vessels are 1.4%, 1.1% and 1.3%, respectively, of oil on board. The regulatory requirement is 1.5%. The existing *Endeavour* and *Alaska* Class vessels both outperform the IMO standard.

It is an interesting side note that restricting cargos to 125,000 ton deadweight to minimize maximum oil spill size increases the expected spill size for these vessels given grounding. For example, if the *Alaska* Class vessel is operated at full load with the corresponding deeper draft, then the mean oil spill size given grounding is actually smaller (1372 m^3 vs. 1984 m^3) than for the light load condition. This is primarily due to the reduced head of oil. The P_0 also decreases slightly (0.816 vs. 0.831) indicating a slightly higher chance of spilling some oil given a grounding. The increased oil carried each trip would reduce the number of trips required, further reducing the overall expected oil outflow (this neglects the higher risk of grounding given the deeper draft).

10.4 STATISTICS OF OIL OUTFLOW

10.4.1 Discussion of Probabilistic Oil Outflow for Baseline, *Endeavour* Class and ATC *Alaska* Class Double-Hulled Tankers

The oil cargo of these Suezmax tankers is approximately 142,700 m^3, and thus the mean outflows for the ATC *Alaska* Class, Polar *Endeavour* Class and Suezmax are 1.4%, 0.8% and 0.9%, respectively, of the oil on board. The *Alaska* Class vessel's performance in this light load condition is a function of the relatively shallow draft combined with a relatively deep hull configuration. The depth over draft ratio for this vessel is 1.9 compared with 1.6 for the other vessels, leading to a greater head of oil when grounded. Note that the differences between these performance levels, as shown in Figure 10-8, are insignificant in comparison with the improvement relative to a single-hull tanker, which is 6.1% .

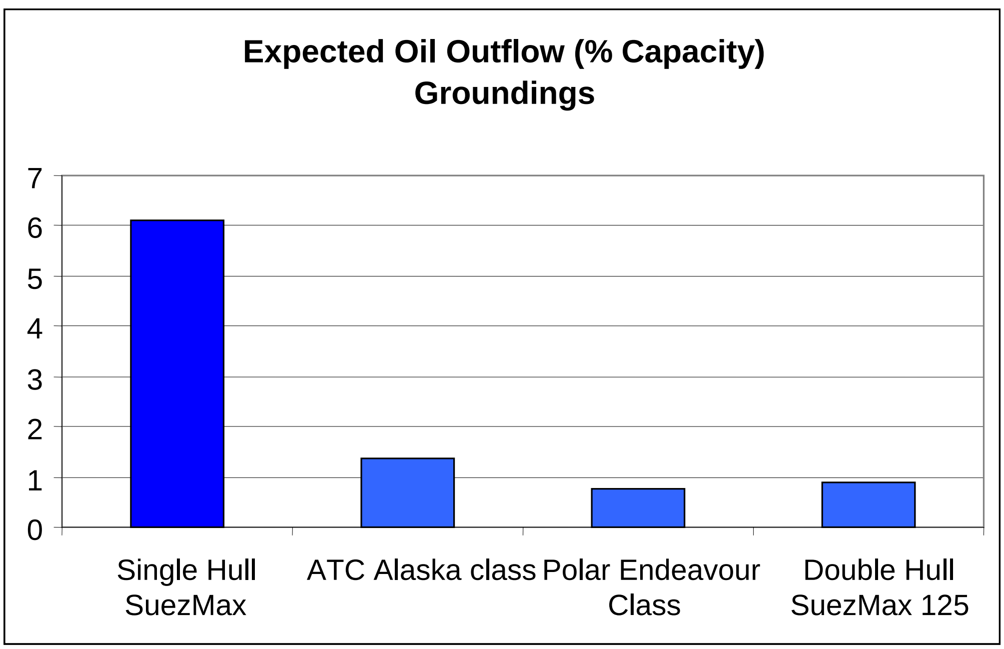

Figure 10-8: Oil Outflow Statistics

11 EFFECTS OF PROPOSED CHANGES ON THE POPULATION OF CAPABLE TUGS IN PUGET SOUND

To understand the effects of proposed changes to the tug escort system on the population of capable tugs in Puget Sound it is important to forecast the number of transits requiring escort, both with and without regulatory changes.

The 2004 Marine Cargo Forecast [Ref. 1] shows an overall increase in the amount of crude oil received in Puget Sound. While the domestic supply of Alaskan crude is expected to decrease, the amount of foreign crude imported into Puget Sound will increase. In the period from 2005 to 2010, when domestic supply will exceed foreign supply, the majority of crude will likely be transported by U.S. flag redundant-system tankers. Starting in 2010, when domestic and foreign crude receipts are approximately equal, slightly less than half the crude will likely be transported by U.S. flag redundant-system tankers. The remaining crude will be brought into Puget Sound using foreign flag single-screw tankers (see Figure 11-1).

Figure 11-2 shows the forecasted number of incoming crude shipments to Puget Sound. These projected transits serve as an indicator for the future of total escorted tanker transits, as outbound product shipments and intra-Sound shifts are highly correlated to the amount of incoming crude. The total escort opportunity for tugs in Puget Sound can reasonably be expected to follow similar trends to those indicated in Figure 11-2.

If the redundant-system tankers (i.e., twin screw, with separated propulsion and steering systems) are exempted from escort, the expected number of transits requiring escort will decrease dramatically. As domestic crude oil supply decreases from 2005 to 2010, the number of calls in Puget Sound by foreign flag (i.e. single-screw) tankers will increase. As much as 20-25% of the foreign flag tanker fleet could be single-hull tankers (Figure 11-3). At the same time that the population of enhanced escort tugs is likely to significantly decline, the calls made by foreign, single-screw vessels will be rising. The result of these trends is that less capable tugs than are currently available will be escorting foreign flag vessels.

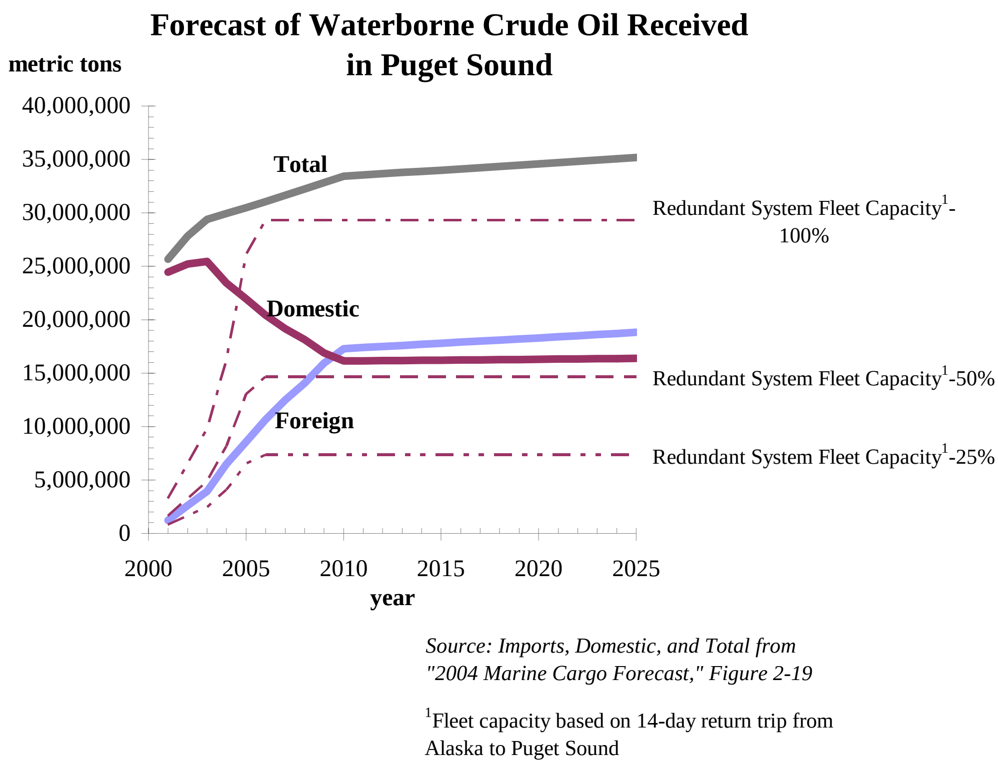

Figure 11-1: Crude Oil Import Forecast – Puget Sound. Foreign imports will increase as domestic supplies decrease. The redundant-system fleet will be capable of handling the domestic crude.

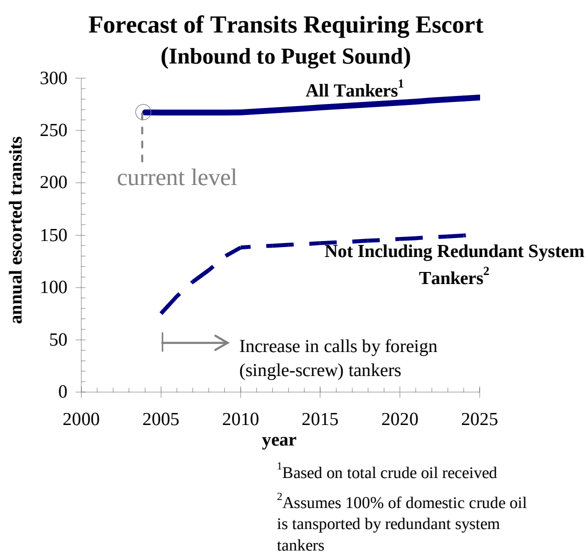

Figure 11-2: Required Transits Forecast. Exempting redundant-system tankers from escort will dramatically decrease the number of transits requiring escort in the near future. In the long term, increased calls by foreign vessels will increase escort.

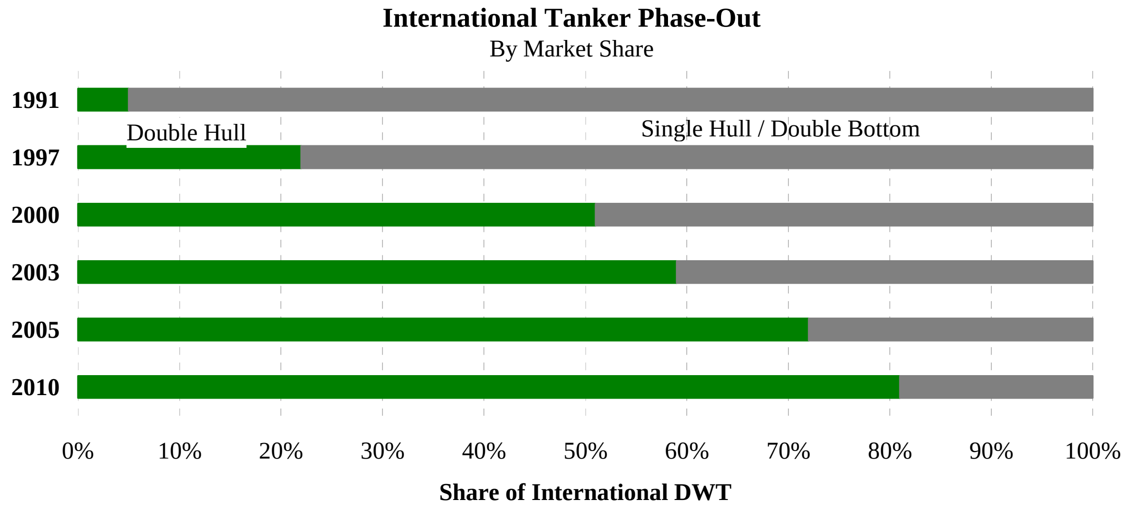

Figure 11-3: Phase-Out Schedule for International Single-Hull Tankers. Presently, 30-40% of international tankers are single-hull or double-bottom (i.e., not double-sided). All international single-hull tankers will be phased out by 2015.

The preceding presentation of the number of projected future tanker calls to service the refineries located on Puget Sound shows that the number of ship calls will be fairly constant. The crude oil traffic is the dominant component of the tanker trade in Puget Sound, but there is a significant volume of refined product along with some shifting of vessels between terminals that increases the total number of tanker escort events. The current traffic levels will remain fairly constant over the next 10 years or so if the escort regulations do not change. However, if the double-hull redundant-system tankers are removed from the tug escort market, then the total demand for escort services could be halved. That would lead to a significant reduction in number of tug escort engagements, and, presuming that tug rates would not change significantly, the business climate might dictate that the operators of special purpose, highly capable, escort tugs find better employment for those assets.

The current escort tug system evolved in response to OPA 90, which mandated that the tanker and tug companies demonstrate that the escort system meet certain performance standards. This approach is significantly different from the Washington state law, which has no performance component. Consequently the Washington state law can be met by tugs that are minimally capable of meeting the horsepower requirements, with no special escort capability. Since the early part of the last decade, the tanker and tug companies have made substantial investment in understanding the tanker-escort system, and this resulted in the design and construction of the unique tugs described elsewhere in this report. The principal element to note is that not only are the tugs uniquely capable, but there is a complete escort system and infrastructure that is supported by the current level of business activity.

If the number of ship escorts were to be reduced by half (or more), then there is a high likelihood that the very capable tugs would be relocated to more attractive markets such as other petroleum ports or possibly to evolving LNG tanker terminal opportunities.

Loss of those tugs would lead to:

1. Loss of ABS rated FI-FI 1 fire fighting capabilities in Puget Sound, since it is the highly capable tugs that have that capability. Tankers, refineries and coastal cities and towns would lose access to a valuable asset.

2. Loss of tugs that can provide berthing assistance in heavy weather for tankers at relatively exposed refinery docks. This can lead to potential damage to refinery equipment and/or to the ships. There is some potential increase in oil spill risk.

3. Loss of the most capable rescue tugs. The escort tugs are able to maneuver adjacent to a stricken vessel in more extreme weather than are conventional tugs. Furthermore, the tug operating companies have equipped their escort tugs for emergency responses.

4. Significant reduction in the level of capability of the tugs of opportunity available on Puget Sound and the Straits of Juan de Fuca. The overall level of business in north Puget Sound means that there are more tugs available in that area than there would be if the tanker escort business devolved to just requiring minimally capable tugs.

A significant issue that could arise is that the current tug escort system that the tug companies now have in place might not be sustainable in a business climate that has significantly less demand for tugs. This is because there are enough tanker calls of all types so that the tug operators can station tugs at strategic locations in anticipation of a predictable level of business. At times this may mean that some assets are underemployed, but in the long term the business activity supports a high level of tug coverage in the operating area. This serves to provide for a relatively high level of emergency tow capability throughout the eastern Straits and northern Puget Sound. Thus the effective response time for any stricken ship is reduced. If the business activity were significantly reduced, the tug assets might have to be re-deployed to other, more attractive markets and the overall level of response and tug capability will be reduced, beyond just the loss of the highly capable tugs.

Another effect of eliminating the requirement for tug escort of redundant-system tankers is losing the speed limit that is currently enforced because of the need to meet the OPA 90 escort rules for tankers. The escort plans for various tankers are based on the ability to assist a stricken tanker along specific routes. Given the assumptions of response time and the other factors affecting an effective escort intervention, the practical effect is that all tankers are limited to specific speeds in the restricted waterways depending on tug capability. If no escort were required, an unescorted tanker would have no speed limit. Whether that would increase risk to the environment in Puget Sound is outside the scope of this study, but clearly *de facto* speed limits are related to the current escort tug system that grew out of OPA 90 performance based requirements.

12 DRAFT RECOMMENDATIONS FOR CHANGES TO TANKER ESCORT FOR DOUBLE HULL REDUNDANT SYSTEM TANKERS

12.1 CONCLUSION

The analysis contained in this study does not show quantitatively that the standard of safety that the Washington State Department of Ecology proposed for this study can be maintained if the requirement for tug escorts for redundant-system tankers is totally eliminated in the waters of Puget Sound currently subject to escort.

The authors of this study do not at this time recommend changes to RCW 88.16.190 that would totally eliminate escorts for redundant-system, double-hull tankers.

A sentinel-tug system is recommended as an alternative to tug escort for redundant-system tankers, provided it is developed as part of an overall system to reduce risk of oil spill for tanker transits of Puget Sound. A sentinel-tug system is not recommended for single-screw tankers.

The authors recommend that the RCW be rewritten to allow for a sentinel-tug alternative escort for redundant-system tankers.

12.2 FINDINGS

Double-hull redundant-system tankers are a significant positive technological step toward improving safety of oil transport in Puget Sound waters and elsewhere. The double-hulls significantly reduce the probability and volume statistics of oil outflow into the environment in the event of a grounding or collision. Their fully redundant-systems for propulsion and steering significantly reduce the probability that a mechanical failure will result in the loss of control of the vessel.

– Finding – These vessels can maintain exceptional control even with the loss of one steering system or one propulsion system. It can be demonstrated that if these vessels are operating in their fully redundant mode and there is a single-system failure (steering or propulsion), even in the severe wind and wave conditions that can occur in Puget Sound, there is a high probability that a grounding can be averted.

However the standard of acceptable risk that the Washington State Department of Ecology set for this study is the level of oil outflow from an IMO minimally compliant, double-hull, single-screw tanker loaded to 125,000 dwt (deadweight tons) *with tug escort*.

– Finding – A tug escort that is configured based on the RCW 88.16.190/195 and, more importantly, in voluntary compliance with the Puget Sound Harbor Safety and Security Committee (PSHSSC) "Harbor Safety Plan" of August 1, 2003 can reasonably be expected to prevent the grounding of a single-screw tanker in the event of a propulsion or steering failure on the tanker.

The PSHSSC is a collaborative organization of public and private maritime organizations. It has as voting members representatives of the following stakeholders: aquaculture, commercial fishing (non-tribal), environmental groups, labor, Native Americans (treaty), passenger-vessel operators, petroleum shippers, pilots, the public, public ports, recreational boaters, the state ferry system, steamship lines, and tug and barge operators. In addition to the stakeholder groups, there are a number of governmental agencies that may serve in a non-voting, advisory capacity.

- Finding – Tug escort of a single-screw tanker may not be able to prevent a grounding if there is a propulsion failure on the tug that is contemporaneous; e.g., within 4 hours of the propulsion or steering failure on the tanker. The incident rate for a two system failure of this type is calculated in this study to be in the range of 3 to 4 x 10^{-7}. (The 4 hour assumption is discussed in Section 10.)

- Finding – Even with a single propulsion failure on the escort tug there is residual capability available to a twin-screw tug to prevent a grounding. Simulations of a rudder failure on a 125,000 dwt Suezmax single-screw tanker transiting at a speed appropriate to the waterway width and escorted by a 6,250 hp twin-screw tug with one engine failure predict that in many locations a grounding can still be prevented.

- Finding – A redundant-system tanker disabled by the failure of both propulsion systems or both steering systems is not expected to be able to avert grounding without tug escort.

- Finding – The incident rate for multiple system failures is several orders of magnitude less than for a single system failure. A two system failure disables a redundant-system tanker if the second failure occurs simultaneously or contemporaneously with the first failure. The estimates developed in this study assume that a second failure within 4 hours of the first failure will, without tug intervention, have a high probably of resulting in a grounding. (It is assumed that a redundant-system tanker with a single-system failure will able to get to an anchorage, to dock or to open water within 4 hours of the failure.)

- Finding – The complete mechanical loss of control of a redundant-system tanker – e.g., contemporaneous loss of both engines or loss of both rudders or one engine and one rudder on opposite sides – is an extremely rare event. It is estimated in this study that the probability of grounding (without tug escort) from these failures within 4 hours of each other is in the range of 3 to 7 x 10^{-7} (3 to 7 in 10,000,000 transits). This is in the range of 1 occurrence in 980 to 2,300 years of transits in Puget Sound assuming an average transit time of 6 hours.

- Finding – The probability of grounding due to propulsion or steering failures of a redundant-system tanker without escort and a single-screw tanker with escort are both very small (between 10^{-7} to 10^{-6} per transit). The redundant-system tanker without escort is estimated to have a slightly higher probability of grounding.

- <u>Finding</u>: A sentinel-tug pre-positioned for transits of redundant-system tankers reduces the probability of grounding compared with the non-escort of redundant-system tankers. The probability of grounding due to propulsion or steering failures of a redundant-system tanker with a sentinel tug pre-positioned at Lawrence Point is estimated to be less than 7×10^{-8} to 4×10^{-7}. This is in the range of 1 occurrence in 1,700 to 9,800 years of transits in Puget Sound assuming an average transit time of 6 hours.

- <u>Finding</u>: The probability of grounding for a redundant-system tanker with a pre-positioned tug at Lawrence Point is slightly less then the probability of grounding for a single-screw tanker with tug escort.

The probabilities of oil outflow from identically configured double-hull, single-screw or double-hull, redundant-system tankers are the same if there is a grounding. Therefore, the difference between escort of single screw tankers and non-escort of redundant system tankers must be found in other factors. The oil outflow rates for the two vessel types can come only from evaluation of both incident probabilities and human factors. The differences are in the incident risk for steering and/or propulsion failures and the risk identified by the statement "can reasonably be expected to avert a grounding" of the tug escort system. As is discussed in Section 10.2, tug escort can prevent grounding in the event of a steering or propulsion failure on a single-screw tanker if there are no human errors in the execution of the emergency response maneuver by the escort tug(s) and no mechanical failures on the tug. It is the successful execution of the emergency maneuver that differentiates escort of single-screw tankers from non-escort of redundant-system tankers.

- <u>Finding</u> – The difference in risk of oil outflow between escorted single-screw tankers and non-escorted redundant-system tankers can be identified only by further study of mechanical failure incident rates and a comprehensive human factors analysis. It is the recommendation of the authors of this report that a decision for or against the elimination of tug escort for redundant system tankers can be made only if a human factors study is undertaken.

This study has also identified other concerns with RCW 88.16.190/195.

- <u>Finding</u> – It is the conclusion of the authors of this study that, standing alone, the requirements in state law RCW 88.16.190/195 are inadequate to ensure a tug escort that can reasonably be expected to avert a tanker grounding in the event of a propulsion or steering failure. RCW 88.16.190/195 and WAC 363-116-500 do not specify a performance standard for the escort tug(s) other than the horsepower requirement. It is the opinion of the authors of this study that the law should, as a minimum, contain provisions that require escort tug(s) to be twin-screw vessels. In addition, it is the opinion of the authors of this study that the law should specify that the selection of escort tug(s) be in accordance with the American Society for Testing and Materials (ASTM) *Standard Guide for Escort Vessel Evaluation and Selection*, Designation: F1878–98, adopted 1998.

It is voluntary compliance with the Puget Sound Harbor Safety and Security Committee (PSHSSC) "Harbor Safety Plan" of August 1, 2003, that provides the standard for tug escort that can reasonably be expected to avert a tanker grounding in the event of a propulsion or steering failure. The Harbor Safety Plan includes standards of care that formalize and document good industry practice, and serves to "complement and supplement future federal, state, and local law." It addresses heavy weather, movement in restricted visibility, anchoring, equipment failures and equivalent levels of safety, tanker escort, underkeel clearance, lightering; towing vessels, direct-drive diesel plants, bridge team management and plan implementation. The completeness, adequacy and effectiveness of the PSHSSC "Harbor Safety Plan" was not evaluated as part this study.

– <u>Finding</u> – The tanker transit speed is not limited by Washington State law. Tanker speed is controlled by RCW 88.16.195, which stipulates that the tanker may not exceed the service speed of the escort tug(s). This type of speed limit is not specific to a particular waterway. It is by voluntary compliance with the PSHSSC "Harbor Safety Plan" that tanker transit is different in different locations within Puget Sound waterways.

  It is possible that redundant-system tankers without escort will choose to increase transit speeds based on other factors. Increasing speed may result in an increased probability of oil outflow from other accidents such as collisions and propelled groundings. The evaluation of tanker speed limits requires further study.

– <u>Finding</u>: – Changes in tanker escort will affect the composition of available tugs in Puget Sound. The change from OPA 90 requirement of a two tug escort for single-hull tankers to the RCW requirement of one tug escort for double-hull tankers is already reducing the demand for tugs. Elimination of tug escort for redundant system ships (which are projected to be able to handle one-half of Puget Sound refining capacity) may eventually result in the highly capable and expensive escort tugs moving to other locations having higher revenue potential. A change in the composition of available tugs in Puget Sound will have an impact on the full range of services that they provide, including harbor services, towing, firefighting, emergency response and participation in the International Private-Sector Tug-of-Opportunity System (ITOS).

This study has also identified the increased probability of oil outflow from Suezmax, Polar *Millennium* Class or ATC *Alaska* Class double-hull tankers in the event of a grounding when they are loaded to 125,000 dwt over the same tankers fully laden.

– <u>Finding</u> – The authors of this study question whether the Federal 125,000 dwt limit for tankers entering Puget Sound minimizes risk in the event of a grounding. The relative risks of oil outflow from more frequent transits of deadweight limited double-hull tankers should be compared to less frequent transits of double-hull fully laden tankers. The authors of this study recognize that the 125,000 dwt limit for tanker entering certain waters of Puget Sound is contained in Federal legislation which supersedes Washington State jurisdiction on this issue. The evaluation of tanker deadweight limits requires further study.

13 CONSEQUENCES OF DRAFT RECOMMENDATIONS

The authors of this study find no consequences of the draft recommendations, as there are no recommendations for changes to the RCW regulation that would eliminate escort for double-hull, redundant-system tankers. However, we recognize that there are consequences to not making changes.

It is the opinion of the authors of this study that possible consequences to not amending RCW 88.16.190/195 include:

- Possible higher cost for shipment of oil into Puget Sound for redundant-system tankers
- Possible diversion of the highly capable TAPS trade redundant-system tankers to California ports where escort for these vessels is not required
- Possible increase in arrivals of single-screw ships to compensate, if a shift of redundant system tankers away from Puget Sound ports occurs
- Possible increased risk of oil outflow if the 125,000 deadweight tonnage restriction is maintained
- Possible deterioration of safety of oil shipment if the voluntary Puget Sound Harbor Safety and Security Committee "Harbor Safety Plan" of August 1, 2003 and the ASTM standard for the selection of escort tugs are ignored. This includes the following possibilities:

    The possibility of escort by single screw tugs

    The possibility of escort by ineffective conventional tugs

    The possibility of escort by tug(s) with inadequate equipment

    The possibility that the valuable pre-escort conference is not continued

    The possibility that tankers will transit at speeds beyond which the escort tugs can be effective

    The possibility that multiple small tugs would be used in a less effective configuration

14 GAPS AND LIMITATIONS ON SYSTEM KNOWLEDGE: RECOMMENDATIONS FOR FURTHER STUDY

The Washington State Department of Ecology requested an analysis comparing single-screw escorted tankers with twin-screw, redundant-system unescorted tankers transiting Puget Sound. A change in scope—from the single-hull vessels originally requested to the single-screw vessels in the final RFP—occasioned a change in analysis. The differences in technical performance of the two systems were found to be not significant, and a more thorough examination of the human factors associated with the two cases is requested.

14.1 PROPOSED WORK

Several steps are involved in assessing the human factors associated with single-screw, escorted tanker transits and twin-screw, redundant-system, unescorted tanker transits in Puget Sound. These tasks include the following:

- Task analysis
- Historical system benchmarking
- Dynamic system modeling
- Assessing human and organizational error

These steps are described in more detail in the following sections.

14.2 TASK ANALYSIS

An analysis of the human and automated tasks associated with single-screw, escorted tanker transits and twin-screw, redundant-system, unescorted tanker transits in Puget Sound provides a baseline for the human factors analysis. In this step, the tasks, sequences and variations in task performance are identified in order to analyze similarities and differences in the two cases. The result of this step provides a baseline for further analysis, and is integrated into the dynamic system modeling effort. An example task analysis list for escort tug intervention is given in Table 14-1.

14.3 HISTORICAL SYSTEM BENCHMARKING

The next step is to evaluate historic and current task performance in the tug escort system. In order to do this, an historical analysis of incidents, accidents and unusual events in Puget Sound would be undertaken in order to identify patterns of incident and accident occurrence in the system, as well as latent pathogens, catalysts and incubation periods. The result of this analysis provides input to the dynamic system modeling described in the next section.

14.4 DYNAMIC SYSTEM MODELING

Once the task analysis and historical system benchmarking are complete, a dynamic system modeling effort is undertaken. The basic technique used is Probabilistic Risk Assessment (PRA), extended to address the dynamic nature of risk in the system.

The dynamic risk modeling includes steps to identify the series of events leading to accidents, estimation of the probabilities of these events, and evaluation of the consequences of different degrees of system failure. These techniques have been successfully used previously in the Prince William Sound Risk Assessment [Ref. 68].

To do this, a computer system simulation previously developed for Puget Sound would be modified to include the tanker transits, other vessels in the area, and the environmental conditions. The simulation is used to determine exposure to risk of escorted and unescorted tankers en route. Exposure to collision risk is based on the number and type of interactions with other vessels; exposure to grounding risk is based on the time actually spent in areas where grounding is possible; allision risk exposure is determined by the number of dockings made; and fire and explosion risk exposure is determined to be a function of the time underway.

Probabilities of occurrences of triggering incidents, and conditional probabilities of an accident given the occurrence of an incident, could be based on data (where available), the analysis just completed or expert judgment where data were not suitable. The dynamic system simulation can then be used to calculate the system risk under different scenarios—a baseline risk scenario, and variations on the baseline, under differing environmental conditions. Finally, the impacts of tug escorts on levels of risk in the system could be estimated by changing parameters or variables in the system simulation. For a more detailed discussion of the modeling process used, see van Dorp, et al. [Ref. 110].

14.5 ASSESSING HUMAN AND ORGANIZATIONAL ERROR

In distributed, large-scale systems with limited physical oversight, assessing the impact of human and organizational error on levels of risk in the system is challenging but important, especially as such error is often cited as a primary contributor to accidents. Thus, in order to analyze the role of human and organizational error in the Washington State tug escort system, an event analysis of accidents could be conducted, following the human and organizational error taxonomy developed by Reason [Ref. 87]. The result of this analysis will be calibrated to the historical system benchmarking results described previously. Comparative analyses between aviation human error studies and the tug escort system can also be undertaken [Refs. 40 & 78].

14.6 SUMMARY

Each of these tasks informs the other. The historical system assessments provide critical input to the dynamic system simulation, specifically in the area of conditional failure probabilities. In addition, the historical system analyses can identify the role of human and organizational error in the tug escort system; this role can be further analyzed in the human and organizational error analysis. The dynamic risk models, the historical system performance assessments, and the human and organizational error analyses can highlight different facets of the tug escort system important to an understanding of human factors in the system, for example training, safety management systems,; and crew certification and re-certification programs. The analysis would also evaluate the role of risk mitigation measures to improve human and organizational performance as a path to mitigating risk in the system.

Table 14-1: Example List of Steps in Escort Tug Emergency Intervention

1. Initial recognition that something is wrong
    a. Engine Failure
        i. alarms
        ii. change in engine sounds
        iii. unordered change in engine RPMs
        iv. unordered loss of speed
        v. call from engine room
        vi. ..
    b. Rudder Failure
        i. alarms
        ii. clicking of heading gyro
        iii. unordered change in heading
        iv. video feed from steering flat
        v. ..
2. Communication of failure recognition to Master/Officer of the Watch/Pilot/etc.
3. Diagnosis failure
4. Check navigational position
5. Determine on-board corrective maneuver
    a. Shutdown propulsion if rudder failure
    b. Order course to be steered if engine failure
6. Determine and Order on-board repair response
7. Determine if tug assistance will be required
8. Call for tug assistance (if required)
9. Determine which corrective maneuver is required
    a. retard (stop ship)
    b. assist (U-turn)
    c. oppose (restore heading)
10. Inform tug
11. Arouse crew to handle tug lines (if required)
    a. Ship's crew assembles on deck
    b.

ON TUG

12. Take pilot's call
13. Sound alarm / alert crew
14. Check navigational position,

15. Check position wrt tanker
16. Determine course to ordered position
17. Quick check of systems (engine, winch etc.)
18. Begin steering toward tanker
19. Crew preparation / prepare lines
20. Maneuver tug into position
21. Pass lines
22. Make fast lines (On Tanker / On Tug)
23. Clear aft deck
24. Maneuver tug into position to apply corrective forces
25. Maximize corrective forces
26. Hold position throughout maneuver
27. Change positions if required / ordered
28. Ease forces so as to not overcorrect
29. Prepare for rescue tow if required

15 OPPORTUNITIES FOR INNOVATIVE APPROACHES TO TANKER ESCORT

15.1 PRE-POSITIONED SENTINEL TUG FOR REDUNDANT-SYSTEM TANKERS

As an alternative to tug escort for redundant-system tankers, this study was asked to consider a pre-positioned sentinel-tug system for North Puget Sound. The proposed system would require that a tug be pre-positioned near Lawrence Point on the eastern tip of Orcas Island in Rosario Strait whenever a redundant-system tanker was entering Puget Sound waters subject to state tug escorts; east of a line between Dungeness Light and Discovery Island Light. This includes the eastern portion of the Straits of Juan de Fuca, Rosario Straits, Guemes Channel and Padilla Bay. The tug would remain on station at Lawrence Point until the redundant-system tanker arrives at Cherry Point or March Point. The tug may be asked to accompany the tanker from Lawrence Point to Cherry Point (or anywhere else in the system) at the discretion of the master and pilot. It is also proposed that there be a tug pre-positioned at Lawrence Point when a redundant-system tanker is shifting between Cherry Point and March Point or visa versa. It is proposed that tug escort continue to be required for all laden tankers transiting to or from South Puget Sound (Tacoma).

The purpose of the sentinel tug is to escort the redundant-system tanker if there has been a single system failure on the tanker while it is in transit in North Puget Sound. It is proposed that the sentinel tug would be notified by the transiting redundant-system tanker if a propulsion or steering failure has occurred. The tug would then be ordered to proceed to rendezvous with the tanker for escort to an anchorage, the dock or open water. It is shown in Section 7 that a redundant-system tanker with the failure of one system is capable of proceeding without significant loss of maneuvering control. It is assumed that the ship would choose to slow its transit speed; however it would proceed under its own power to an anchorage, the dock or open water.

The time required for the sentinel tug to reach a rendezvous with the tanker depends on the speed of the tug, state of the tidal current, wind/wave conditions and the speed, direction and location of the tanker. Fig. 15-1 shows distance contours for 1 n.m. and half-hour intervals assuming a 10 knot speed over ground. From the Lawrence Point pre-positioning location, the whole of North Puget Sound can be reached within 2 hours. It is during this two hour period that the redundant-system tanker is at risk for a second failure of the propulsion or steering system. The frequency of a second failure within a specified time period from the first failure is calculated using the following formula.

$$P(A,B) = \{1 - e^{-\lambda_a T_a}\}\,\{1 - e^{-\lambda_b T_b}\}$$

where *P(A, B)* is the probability of two failures *A* and *B*, λ_a, λ_b are the failure frequency rates for *A* and *B* (in incidents/hr) and T_a and T_b are the time intervals in which the failure occurs. In the calculations shown in Table 15-1 we have used T_a at 6 hours (the nominal average transit time for a tanker in Puget Sound) and T_b is the time between the first and the second failure that could initiate drifting of the disabled vessel.

A comparison of the proposed sentinel-tug system for redundant-system tankers and escort of single-screw tankers is given in Table 15-1.

Table 15-1: Comparison of Scenarios for Proposed Sentinel Tug System and Existing Escort One-Tug System Tug System

	Sentinel Tug	**Escort Tug**
For which ships:	Redundant-system double-hull	Single-screw double-hull
When:	For Rosario, Guemes, Padilla Bay Transits – not lower Puget Sound	All of Puget Sound
Tug location:	Pre-positioned at Lawrence Point	Next to tanker while transiting
Tug type:	Twin-screw conventional of specified horsepower or purpose-designed escort tug	RCW minimum compliance or purpose-designed escort tug
Pre-positioning: (inbound)	Tug is pre-positioned when tanker arrives at Port Angeles	Tug starts escort at Dungeness / Discovery line
Tug Speed:	Average 10 kts over ground (currents may be adding or hindering speed)	Same as tanker (generally less then 12 knots)
Pre-transit conference:	Via radio to tug at sentinel pre-positioned location	Same as current practice
Single system failure scenario	Either one engine failure or one rudder failure with voluntary engine shutdown on same side	Either engine failure or rudder failure with voluntary engine shutdown
Single system failure frequency rates:	PS VTS data: propulsion: $8x10^{-5}$/hr, steering: $6x10^{-5}$/hr PWS study data: propulsion: $14x10^{-5}$/hr, steering: $6.5x10^{-5}$/hr USCG CASMAIN data: propulsion: $6.5x10^{-5}$/hr, steering: $3x10^{-5}$/hr	
Tanker response to single system failure:	Continues transit at reduced speed; radios tug to come escort	Ship is disabled; radios tug to begin emergency response maneuver.
Tug response:	Tug departs sentinel location	Tug maneuvers from escort position
Tug arrival time: (see Figure 15-1)	Varies; depending on failure location; ~15 min. to 2 hours	~2 minutes

Table 15 –1 (cont.)

	Sentinel Tug	Escort Tug
What does tug do:	Escorts or assists tanker to dock, anchorage or to open water	Stops tanker, rigs main towline, begins tow to anchor or to open water; or holds tanker until second tug arrives
Second Failure Scenario:	Second failure on tanker before tug arrives, resulting in loss of both engines or both rudders or engine/rudder on opposite sides. Ship is disabled	Failure of one of the two tug engines or tug steering system during escort maneuver or before the tanker is towed to anchor or open water.
What happens if there are two failures?	Tanker drifts until sentinel tug arrives	Tug has some remaining capability if single engine failure occurs; Or no capability if steering failure occurs, tanker may drift until second tug arrives.
Time interval for second failure could initiate drifting of the disabled tanker:	Before sentinel tug arrives; between 1/4 and 2 hours; (coming from Lawrence Pt)	Before reaching anchorage or open water; Or before second tug arrives; between 1 and 4 hours
Frequency of contemporaneous failures:	Within 2 hrs: < $7x10^{-8}$ to $4x10^{-7}$ (depending on choice of incident rate)	Within 4 hrs: < $3x10^{-7}$ to $8x10^{-7}$ (depending on choice of incident rate)
Issues related to the probability of grounding:	Depends on wind and currents, and on arrival time of sentinel tug and time to rig emergency tow	Depends on wind and currents, one-engine capability of escort tug, and on arrival time of second tug and the time to rig a second emergency tow
Probability of grounding †	On the order of 1×10^{-7}/transit (1 per 10 million transits)	On the order of 2.5×10^{-7}/transit (2.5 per 10 million transits)

† *(The probability distribution of drift time to grounding has not been included in the tabulated estimate of the probability of grounding. Including this time as additional element in the time for the sentinel tug to make up a tow to a drifting redundant-system tanker or for the second tug to arrive to assist a partially- or fully-disabled escort tug of a drifting single-screw tanker, would reduce the estimate of the probability of grounding. However, the reduction would be insignificant with respect to the order of magnitude of the incident rate.)*

Table 15 –1 (cont.)

	Sentinel Tug	Escort Tug
Finding:	Sentinel-tug system for redundant-system tankers results in slightly lower probability of grounding than tug escort for single-system tankers (assuming escort tug with loss of one engine cannot prevent a grounding).	
Conclusion:	Further differentiation between the two systems would require a comprehensive human factors analysis	
Observations:	The sentinel-tug system for redundant-system tankers is not as risk reducing as escort of redundant-system tankers. The difference is probably immeasurable. (Not calculated).	A second tug should be called at the same time the escort tug is ordered to respond. This is to cover the possibility that there is a system failure on the escort tug. ††
Other issues:	Loss of auxiliary bridge function (value could be determined with a comprehensive human factors analysis)	Probability of tug – tanker collision
Simplifications:	Time to drift grounding has not been calculated. This additional time is available to the sentinel tug for arrival and hook-up.	Probability of momentum or drift grounding if escort tug loses half of its propulsion or all of its steering before second tug arrives has not been calculated.
Laden tanker transit to/from Tacoma:	Tug escorts tanker	Tug escorts tanker

†† *This issue should be considered for inclusion into the Harbor Safety Committee's Standard of Care.*

15.2 RECOMMENDATION

A sentinel tug should be considered as an alternative to tug escort for redundant-system tankers provided it is developed as part of an overall system to reduce the risk of groundings due to propulsion and/or steering failures on transiting tankers. This system can be developed under the auspices of the Puget Sound Harbor Safety & Security Committee (PSHSSC) or another stakeholder organization. For example, this recommendation can be implemented by deleting Section (2)(a) from RCW 88.16.190, adding a requirement for a sentinel tug for transiting redundant-system tankers and incorporating a sentinel-tug system into the PSHSSC "Harbor Safety Plan",16.88.190.

In addition, it is recommended that the RCW be amended to require biannual review of the Puget Sound "Harbor Safety Plan," with the results submitted to the legislature.

A sentinel tug system is not recommended for non-redundant-system tankers.

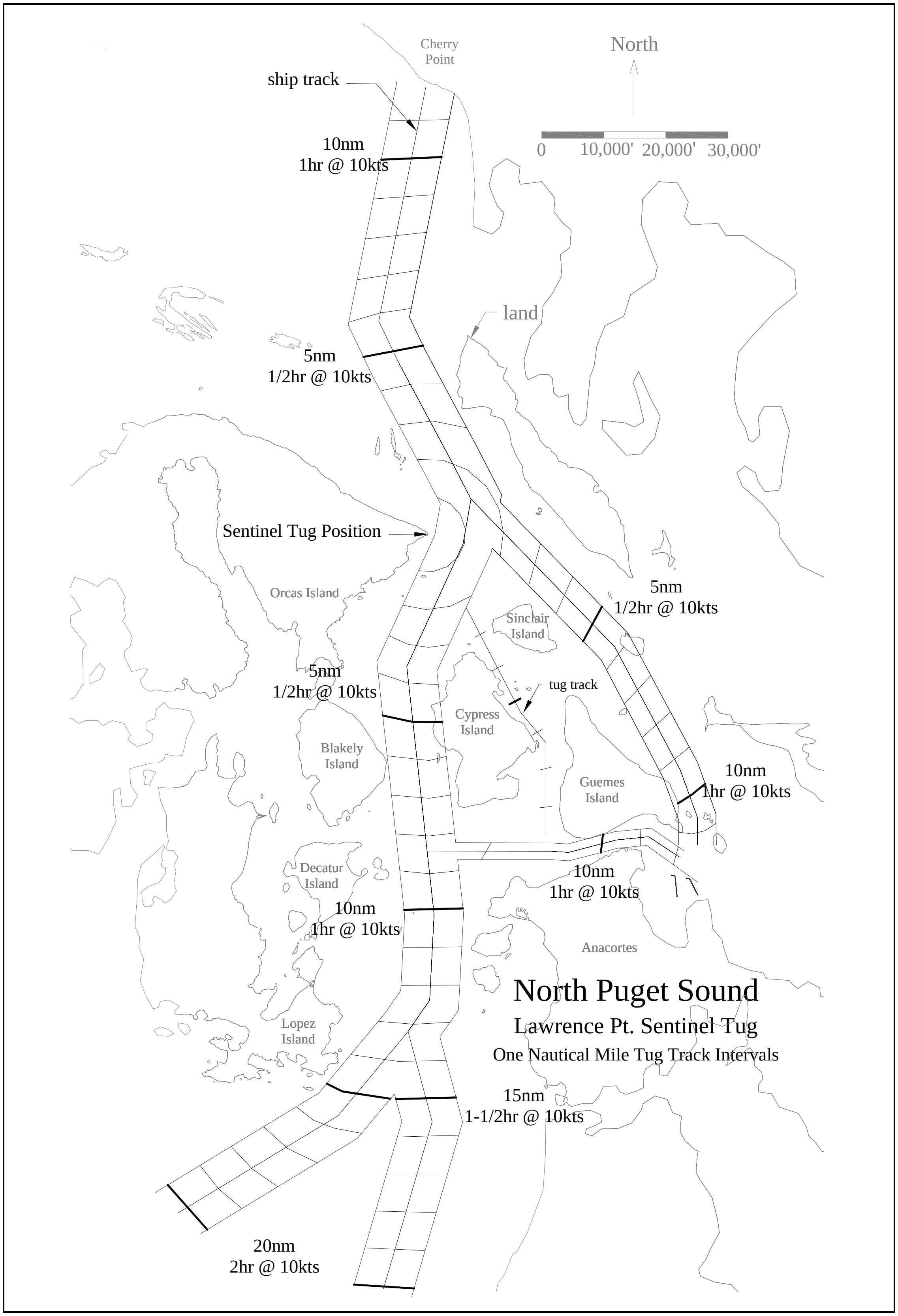

Figure 15-1: Tug Travel Distances and Times at 10 knots with Sentinel Tug Located at Lawrence Point

15.3 SENTINEL-ESCORT VESSEL

An option exists to compensate for the loss of the auxiliary bridge function (extra eyes and ears) that an escort tug provides if continuous tug escort is eliminated for redundant-system tankers. These auxiliary functions could be provided by an escort vessel that is not necessarily a tug. The principal advantage would be cost and speed, and possibly improved port security. It is possible that a sentinel-escort vessel would be less expensive to procure and operate than an escort tug. It is also possible that such a vessel could be located, or designed and built, that would be able to travel at higher speeds. This possibility would reduce transit times for tankers running between Port Angeles and Cherry Point.

The role of the sentinel escort would be to double-check the tanker master and pilot on navigational issues. It may check ahead for other traffic, pleasure boats, nets, fish boats and the state of buoys. The sentinel escort vessel could carry oil-spill boom and other first response oil-spill equipment.

The sentinel-escort vessel would not need to convoy in close proximity to the transiting tanker. Unlike an escort tug, there is no requirement that it be able to come alongside quickly and initiate an emergency response maneuver. The possibility for increased distance between the sentinel-escort vessel and the tanker reduces the possibility of tanker-tug collision that is a risk in the current escort system.

The advantages, disadvantages and cost-benefit analysis of a sentinel-escort vessel should be undertaken if escort is eliminated for redundant-system tankers. Specifications and operating practice for such a vessel could be developed by an organization like the Puget Sound Harbor Safety & Security Committee.

15.4 INNOVATIONS SINCE OPA 90

Since the performance-based regulations of OPA 90 were enacted, there have been several innovations in the tanker escort system. These include:

- **Rendering winches:** These winches can render (pay out) and recover (take up) line while maintaining a constant tension in the tow line. This allows the line-winch system to account for relative motions of the tanker and tug without having to slacken and tighten the line.

- **Escort manuals:** These manuals are provided to and used in the training programs of tanker and tug companies for their key personnel for tanker escort. The manuals provide an agreed-upon standard procedure and educate key operating personnel about the capabilities and limitations of the escort tug in a wide range of scenarios.

- **Improved communication:** A pre-escort conference between the tanker and tug is compulsory. The pre-escort conference is widely considered a significant safety enhancement because the procedure for the transit is discussed, as well as the protocol for emergency response. This type of pre-maneuver conference has become common practice in assisted maneuvers other than tanker escort. The overall system safety is enhanced because everyone is "on the same page."

- Other improvements include the use of full-mission maneuvering simulators and bridge team management programs.

15.5 ADDITIONAL INNOVATIONS

There is opportunity for innovations to enhance the safety of the tanker escort system. Some of these innovations could include:

- **Improved Line Handling:** During transits in Puget Sound, tankers engaged in the TAPS trade hang a line over their stern that can be quickly received by a tug and connected to the tug's towline in case of an emergency. A similar system could be adopted and standardized for all laden tankers transiting Puget Sound. Minimizing the time required to make up a towline is a crucial step toward enhancing the tanker escort system safety. An opportunity for innovation exists in devising ways to pass leader lines quickly from the escort tug to the tanker.

- **Further Improvement of Communication:** Designating a VHF channel to be reserved solely for communication between tankers and tugs during escort would ensure clear and timely communication between the two vessels, which would enhance the tanker escort system safety and potentially port security.

16 CONCLUSIONS

The analysis contained in this study does not quantitatively show that the standard of safety proposed by the Washington State Department of Ecology for this study can be maintained if the requirement for tug escorts for redundant-system tankers is eliminated in the waters of Puget Sound currently subject to escort. The authors of this study do not at this time recommend changes to RCW 88.16.190 that would totally eliminate escorts for redundant-system double-hull tankers.

The analysis contained in this study does quantitatively show that the standard of safety proposed by the Washington State Department of Ecology for this study can be maintained if a sentinel-tug is pre-positioned at Lawrence Point during the transit of a redundant-system tanker in North Puget Sound. The sentinel-tug would replace continuous escort for redundant-system tankers in the escorted waters of the Straits of Juan de Fuca, Rosario Straits, Guemes Channel and Padilla Bay. The sentinel-tug system is recommended provided it is developed as part of an overall system to reduce the risk of groundings due to propulsion and/or steering failures on transiting tankers.

A sentinel tug is not recommended for non-redundant-system tankers.

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APPENDICES

The appendices for this report can be found at the Washington State Department of Ecology; Spill Prevention, Preparedness and Response web site. This web site contains a link to this report and to the appendices to this report. The web address is:

http://www.ecy.wa.gov/programs/spills/spills.html

The appendices for this report are as follows:

Appendix A: Socioeconomic Values Protected

Appendix B: Puget Sound VTS Incident Summary

Appendix C: IMO Guideline Oil Outflow Methodology

Appendix D: MARPOL Amendments on the Phasing Out of Single-Hull Tankers

Appendix E: Presentations at Public Meetings